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Industrial Hygiene Techniques in the Decontamination of a Building Contaminated with Radium

REYNOLD L. HOOVER

Health and Safety Department, Combustion Engineering, Inc., Nuclear Division, Windsor, Connecticut

Radium contamination had built up in a large office building over a period of forty years. The radiation levels were as high as 500 mrem/hr with alpha contamination >40,000 d/m/100 cm². From an industrial hygiene point of view, the major problems associated with the decontamination of the facility were: (1) keeping from tracking contamination into clean areas, (2) keeping the workers from becoming contaminated, (3) keeping the workers' exposure to external ionizing radiation as low as possible, (4) keeping inhalation and/or ingestion of radium from occurring, and (5) keeping future inhabitants of the building from receiving any radiation exposure as a result of their working in the building. The building was decontaminated to a maximum of 0.2 mr/hr at a distance of one foot from any surface and the radon plus its daughter's activity was reduced to levels of less than 10^{-9} μc/cc.

IN the spring of 1959, the Health and Safety Consulting Service of Combustion Engineering, Inc. agreed to decontaminate portions of a five story office building that was contaminated with radium. The contamination had built up over a number of years, dating back to near the turn of the century when a group of investigators were performing experiments on animals to see which diseases could be cured with radium. The same group was also preparing radium capsules and radium saline solutions which were ultimately used by physicians in treating patients. (It might be noteworthy to mention that Madame Curie visited these early investigators and reviewed their work.) In later years radium was prepared for the radium dial industry and still later the laboratories were used to prepare zinc sulfide.

An initial survey in the rooms affected indicated a general radiation flux ranging from 5 to 500 mrem/hr. The alpha levels ranged from 1000 to >40,000 d/m/100 cm². Most of the contamination was fixed in the flooring, plaster, and woodwork. It became apparent that the usual decontamination techniques involving washing and surface removal would have little effect, and a complete renovation was necessary.

Hot plates located in hoods were virtually buried in radium and zinc sulfide. Housekeeping was obviously lacking as junk was piled in almost every room. Conditions such as these compounded the decontamination problem and added to the amount of contaminated waste, the air dust levels and the tracking of contamination from one room to another.

From an industrial hygiene point of view, the major problems associated with an undertaking such as this were to:

(1) Keep from tracking contamination into clean areas.
(2) Keep the workers from becoming contaminated.
(3) Keep the worker's exposure to external ionizing radiation as low as possible.
(4) Keep the inhalation and/or ingestion of radium from occurring.
(5) Keep future inhabitants of the building from receiving any radiation exposure as a result of their working in the building.

In order to keep from tracking contamination, a control point was established where shoe covers and rubbers were put on, worn in the highly contaminated areas, and taken off when leaving to go into a clean area. In addition, roofing paper was laid down in hallways, and the rooms in which work was going on were kept closed. Besides these measures, all of the so-called clean areas and hallways were scrubbed once or twice daily and contaminated clothing never left the premises.

Still another way in which the spread of con-

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tamination was controlled was through the establishing of a "headquarters" room, out of which the decontamination crew worked. This room was located on the clean side of the control point, and as the decontamination progressed, the "headquarters" changed location. Every attempt was made to work out of as clean an area as possible and toward the room or area which was being decontaminated. The headquarters was decontaminated three or four times daily and working tools, as well as equipment which was stored there, was all decontaminated prior to being brought into the room.

The decontamination crew was kept from becoming contaminated by: (1) instilling in them beforehand the necessity for personal hygiene; (2) requiring them to wash their hands after leaving a work area; (3) requiring a shower at lunch time and again at night; (4) giving each man at least one, and sometimes three, changes of protective clothing daily, i.e., coveralls, head covering, gloves, shoes and socks; and (5) teaching the men the proper way to remove contaminated articles of clothing.

Actually, as it turned out, it was not too difficult to keep the personnel exposure to ionizing radiation fairly low. The reason for this was two-fold: (1) the supplied air breathing equipment which was used was only good for about fifteen minutes operation, and at the end of that time the men working in the area were relieved so that nobody was continuously exposed; and (2) as the decontamination progressed, the dose rates were lowered. The highest accumulated exposure over a twenty-week period was 805 mrem.

The air dust problem was recognized from the beginning to be of greatest concern. The difficulty, of course, was in getting an air sample analyzed without waiting for the radon and its daughters to decay. If the radon concentration was greater than a factor of two below 3×10^{-8} μc/cc (33,000 d/m/m^3), or if any radium was suspected in the air, Scott Air Paks were used. If the radon levels were low and radium was suspected in the air, half face masks were used. If the radon was below the limit, and radium was not suspected in the air, no respiratory protection was used. Before going into a discussion on radon, it must be pointed out that the word "suspected" is used as a prefix for radium because the background was so high on the counting equipment that the radium tolerance of 3×10^{-11} μc/cc could not be detected.

Radon is generally collected in a gas sampler and counted. (Some workers use the vibrating reed electrometer.) It was decided, however, that it might be better to count the beta activity from the radon daughters than the alpha activity in order to minimize errors from radium that might be in the sample.

The following assumptions and techniques were used: (1) As radon passes through a filter paper it leaves its daughters behind on the paper. (2) Secular equilibrium is assumed to exist in the air so that the disintegration rates of each of the daughters is equal to that of the radon. (3) Radium B and radium C are the only beta emitting daughters. (4) Once the particulates are on the filter paper, equilibrium conditions are disturbed for the chain Ra A $\rightarrow$ Ra C' due to the loss of the radon parent. (5) Because the daughters are decaying, one must relate the beta activity at some time after sampling to the radon activity at the time of sampling. (This must be calculated for Ra B and Ra C.) It is found through calculation that the beta activity on a filter paper, counted immediately after sampling, equals one-half the radon activity at the sampling time. A series of calculations can be made and the radon activity at sampling time can be plotted against time after sampling. A gast pump and filter holder system was used to collect the samples and the filter paper used was the HV-70.

In practice air samples ranged from 213 to 26,000 d/m/m^3; however, radium was not found in air samples that were less than 1793 d/m/m^3. (Samples with less than this amount decayed to background in 30 hours after the initial sampling and had no radium in them when analyzed in the laboratory.) It should also be pointed out that whenever a removal operation was carried out respiratory protection was used.

As a check on the effectiveness of the air sampling program, urinalyses for radium were run on each of the workers at least once a week. It was found that a significant increase occurred and definite peaking was observed from time to time. Upon investigating these peaks, it was learned that although supplied air masks and half face masks were worn in the rooms being decontaminated, workers who were making surveys in adjacent, clean rooms, and workers who were scrubbing the hallways did not wear respiratory protection. Although these particular jobs did not require masks, the dust from the room being worked on travelled to the surrounding areas and was subsequently inhaled by these workers. The urine samples of the men in the area where respiratory protection was worn were lower than the urine samples of those who were not in the highly contaminated areas. The

difficulty in controlling this secondary exposure was complicated by the fact that it took at least two weeks before the results of the urine samples were known.

The building was decontaminated to as low a level as possible after about six-months' work. On some of the floors, two inches of high density concrete was required in order to bring the final radiation levels after restoration in any area down to a maximum of 0.2 mr/hr at a distance of one foot. The radon plus its daughter activity was reduced to levels of less than 10^{-9} μc/cc.

Radiation Codes and Handbooks

THE AMERICAN STANDARDS ASSOCIATION codes and National Bureau of Standards handbooks in the field of radiation protection are items of increasing inquiry, use, and interest to AIHA members. The Standards Committee of AIHA has provided the following list of these items:

ASA Standard for *Radiation Symbol* N2.1-1960 at 50¢

ASA Standard for *Radiation Protection in Uranium Mines and Mills (concentrations)* N7.1-1960 at $2.00

ASA Standard S1.1-1960 for *Acoustical Terminology* at $4.50

ASA S3.2-1960 for *Monosyllabic Word Intelligibility* at $1.35

ASA S3.1-1960 for *Background Noise in Audiometer Rooms* at $1.00

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionucleides in Air and Water for Occupational Exposure National Bureau of Standards Handbook No. 69 at 35¢

Measurement of Neutron Flux and Spectra for Physical and Biological Applications NBS Handbook No. 72 (cost not known)

Protection Against Radiations from Sealed Gamma Sources NBS Handbook No. 73 at 30¢

Anachem Conference

THE NINTH DETROIT ANACHEM CONFERENCE sponsored by the Association of Analytical Chemists, Detroit, Michigan, will be held again in the McGregor Memorial Conference Center at Wayne State University on October 16, 17 and 18, 1961. Papers in the fields of instrumental, gravimetric and titrimetric analysis; fluorometry; polarography; emission, absorption, and x-ray spectroscopy; mass spectrometry; and chromatography are being planned. Special symposia will be held on EDTA, clinical chemistry, and radiochemistry methods. A feature of the program will be the presentation of the Anachem Award for Outstanding Achievement in Analytical Chemistry to Dr. I. M. Kolthoff of the University of Minnesota.

For further information write to P. N. Burkard, Program Chairman, Ninth Detroit Anachem Conference, Wyandotte Chemicals Corporation, Wyandotte, Michigan.

Air Sampling and Analysis of Lead on Paper

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A new procedure for the analysis of air-borne lead, based on chromatography, is described. Samples collected on filter paper tape are treated with hydrochloric acid-butanol reagent to prepare the chromatogram. Spraying with a dithizone reagent develops the color. The system is applicable to other metals.

AN economical, reasonably accurate method for measuring air-borne lead, as well as some other metals, has been developed using the principles of paper chromatography. The advantages of this procedure are based on the specificity and sensitivity which can be obtained by the proper choice of developing solvents and color reagents. In addition, special purification of reagents, usually required for trace lead analysis, is not necessary as the lead in the reagents does not contribute appreciably to the apparent lead level in the sample.

The procedure is described step by step for lead in the following paragraphs. It can be used for other metals, including bismuth, cadmium, cobalt, copper, manganese, mercury, and tin. A similar approach should be useful for a wide variety of air-monitoring problems.

Collecting the Sample

Manual samples are obtained by use of glass or aluminum flanges, holding the filter paper tape and connected to a source of vacuum through a flow meter. A wide variety of conventional equipment can be readily modified to permit the use of a paper tape rather than a disc. A very wide spread of concentrations can be handled by proper selection of sampling rate through control of the lineal flow rate and/or the sampling area.

Several automatic paper tape samplers are available commercially, and can be easily adjusted to the requirements of this procedure. Such samplers are in general dependable, low in cost, and will provide round-the-clock coverage, unattended.

Selecting the Paper

A number of investigators have studied the efficiency of filter paper for collecting lead dusts and fumes.[1, 2, 3] For the preliminary tests, Whatman No. 1 Filter Paper, which has been used for inorganic chromatography, was selected.[4, 5, 6] Later tests indicated Whatman No. 54 is superior, while Whatman No. 4, 11, and 20 were not as satisfactory.

Selecting the Solvent

For maximum utility, all forms of lead samples must respond to the solvent in the same manner. Therefore, the solvent must be able to dissolve lead encountered as the carbonate, sulphate, chromate, sulphide, arsenate, various oxides, metallic dusts and fumes. In addition, it must provide adequate separation from interfering substances, and eliminate any irregular distributions on the paper such as tailing and comets which would interfere with the quantitative estimation.

Two solvent systems appear suitable for this procedure. One consists of normal butanol saturated with hydrochloric acid, and the other normal butanol saturated with acetic acid. A series of qualitative tests led to the selection of *n*-butanol with 3*N* aqueous hydrochloric acid, and *n*-butanol with 20% aqueous acetic acid for further tests. At the same time, it was found that lead behaved in the same manner with the solvents, whether it was present as the soluble salt, the sulphide, the various oxides, or the fumes from burning solutions of tetraethyl lead in alcohol.

The acetic acid solvent failed to separate lead from a number of metals as shown in Table I and in Figures 1 and 2. In addition, when the amount of lead exceeded five micrograms there was noticeable tailing. The hydrochloric acid solvent did not tail with quantities as great as 50 micrograms of lead, and only silver and large amounts of copper interfered. The copper can be separated by use of a longer developing period, but the silver streaks the length of the chromatogram and would obscure small amounts of lead.

* Present address: Standard Oil Company of California, San Francisco 20, California.

TABLE I

	Dithizone Color		Experimental *Rf**	
	Unbuffered	Buffered	HCl	HAc
Bismuth	Purple	Purple	0.8	0.9
Cadmium	Lavender	Purple	1.0	0.2
Cobalt		Purple	0.9	0.2
Copper	Lavender	Purple	0.2	0.2
Lead	Pink	Cinnabar Red	0.24	0.2
Manganese		Lavender	0.1	0.2
Mercury	Orange	Red	1.0	0.7
Silver		Purple	Comet	
Tin	Pink	Purple	1.1	0.8

* Ratio of distance traveled by metal to distance traveled by solvent.

The hydrochloric acid-butanol solvent was selected as best meeting the criteria established. In using this solvent, an irregular discolored band follows the solvent front, and turns bright pink on color development. This band, which does not occur with acetic acid, does not interfere and can be eliminated if necessary by washing the paper with solvent before use.

Developing the Chromatogram

Detailed instructions on paper chromatography are readily available in the literature.[4, 5, 6] Either ascending or descending techniques may be used. In this study, standards were run with each sample to eliminate the need for close control of temperature and other variables which could affect the rate of transference of the lead.

Selecting a Color Reagent

The color reagent is used to identify the lead by the characteristic color formed, and to permit estimation of the amount present. A large number of reagents have been suggested in the literature. Tetrahydroxyquinone, which is reported to give positive results on lead collected on paper as the chromate, dioxide, tetroxide, monoxide, iodide, sulphide, solder, and type metal fumes, has a sensitivity of 2 to 3 micrograms.[10, 11] Bismuth, copper, tin, and iron do not interfere. Ammonium sulphide was shown by test to have a sensitivity of about two micrograms. Dithizone and rhodizonic acid both have a sensitivity of about 0.1 microgram. These two reagents were selected for further study. The effect of pH was observed by spraying the chromatograms with buffer solutions.

Rhodizonic acid is violet at pH 7.0 and scarlet red at pH 2.8. Very few metals interfere, but the color fades rapidly on standing, particularly on paper. Dithizone as a 0.1% solution in chloroform, gave the best results at a pH of 11.0. The colors developed changed very little in six months, and were still visible after three years. The pH is easily adjusted by spraying with a aqueous 0.1 *N* solution of sodium or potassium carbonate following the treatment with the di

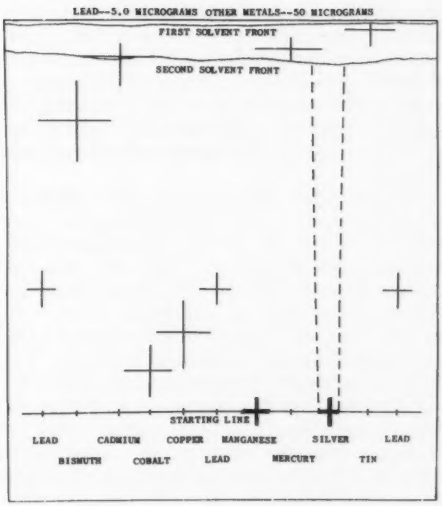

FIGURE 1. The chromatographic behavior of lead and some other metals in 3*N* HCl-n-butanol solvent.

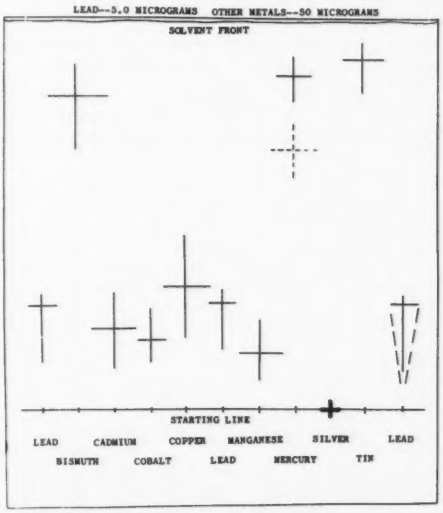

FIGURE 2. The chromatographic behavior of lead and other metals in 20% acetic acid-n-butanol solvent.

thizone. The change in background color on the chromatogram from green to pale orange provides a built-in indicator. The papers must be carefully dried, however, before spraying, or some acid will remain from the developing step which will require excess carbonate solution and thereby spoil the chromatogram by dripping or running.

The dithizone reagent gives colors with bismuth, cadmium, cobalt, copper, manganese, mercury, silver, and tin. This is advantageous, since the lead is already separated from these elements by the chromatographic developing step, and therefore the same chromatogram can be used to determine all simultaneously, provided allowance is made for the difference in sensitivity. This is shown schematically in Figures 1 and 2. Fifty micrograms of each metal was mixed with five micrograms of lead in preparing these chromatograms to determine whether they might interfere. Only silver, as already noted, interferes with the solvent system selected.

Quantitative Estimation

Many different procedures have been suggested for estimating the quantity of materials on a chromatogram. It is always possible to cut out the appropriate area and analyze by conventional chemical means. Direct procedures, however, are based chiefly on the appearance of the paper and include measuring the area of the spot, the length of a strip, the maximum color density, and the

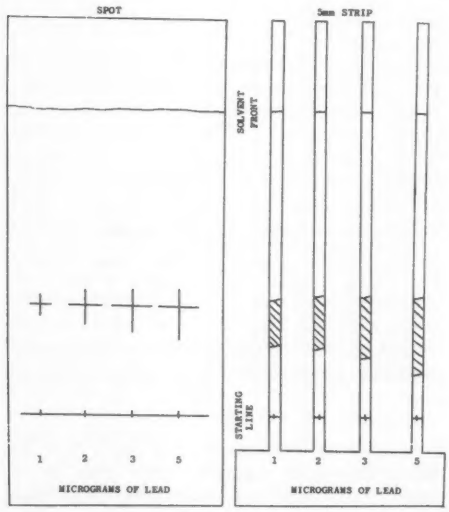

FIGURE 3. Quantitative estimation of lead nitrate in 3*N* HCl-butanol solvent.

TABLE II
Spot Size Technique

Lead (micrograms)	1	2	3	5	9	11
Run 1 Length (mm)	10	13	16	19	23	28
Width (mm)	10	13	16	16	16	17
Run 2 Length	11	13	15	19	22	27
Width	10	10	13	15		
Run 3 Length	9	15	15	18		
Width	8	10	13	17		

TABLE III
Strip Length Technique

Lead (micrograms)	1	2	3	4	5
Length of strip-mm.					
Run 1	18	19	22	30	33
Run 2			24		32
Run 3			28		32

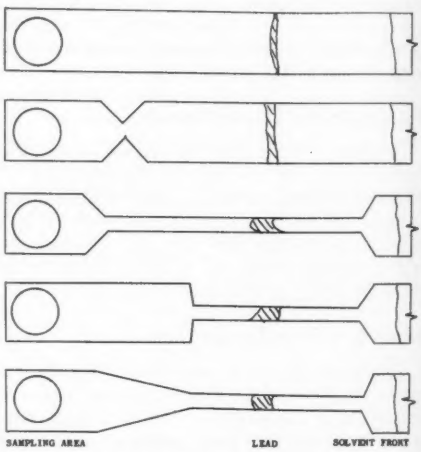

FIGURE 4. Chromatographic concentration techniques for lead in 3*N* HCl-n-butanol solvent.

TABLE IV
Chamber Study

Sample	Lead (micrograms) by chromatography	Lead (micrograms) by dithizone	Lead concentration milligrams/meters³	
			Chromatog.	Dithizone
1	2	1.5	0.03	0.024
2	3	1.5	0.05	0.030
3	3	2.1	0.10	0.066
4	3	2.0	0.10	0.063
5	10	9.2	0.32	0.29
6	10	8.5	0.32	0.27

product of area and density. Densitometers, planimeters, and photometers have been used to obtain more objective results. Only the simplest procedures are considered here.

Two procedures are shown schematically in Figure 3. Tests show that spot size increases with the amount of lead present. Similarly, strips of limited width show an increase in length with increasing quantities of lead. The results on both spots and strips are shown in Tables 2 and 3. It is important to note that as the quantity of lead increases, the width of a spot approaches a constant, and the length governs the result. These increases in general are not linear, but no simple exponential relationship is apparent. More careful technique improved the quality of the data, but in any case standards had to be run with the samples or large errors resulted.

Field Studies

In order to evaluate the procedure, duplicate ambient outdoor air samples were taken using manual samplers. The results obtained polarographically indicated 8.0 micrograms of lead, compared with 6.9 micrograms of lead obtained by the chromatographic procedure. The solvent front and original sampling area from the chromatographic procedure contained less than 0.5 micrograms of lead, the limit of sensitivity in this test.

The sampling area should be small for sensitive and accurate chromatography, but large in order to obtain rapid samples at very low concentrations. Several tests were made using a large sampling area, followed by concentration directly on the paper during the chromatographic step as shown in Figure 4. Shaping the paper is seen to influence the distribution of lead, and appears promising as a method for resolving this sampling problem, as well as improving the accuracy.

A chamber study was made on the combustion products of the solution of tetraethyl lead in alcohol. Lead fume concentrations were established by burning solutions of different strength and by controlling the chamber ventilation rate. Simultaneous samples were taken for the chromatographic procedure and for a mixed-color dithizone reference procedure. The agreement of the two methods showed that only one-third of the calculated lead fume concentration actually was achieved. The results are given in Table 4. The fixed-width strip technique was used with standards run at the same time. Where the length of the strip was not uniform, a five-point traverse was made and the results averaged.

Summary

A new procedure for the analysis of air-borne lead has been developed, based on chromatographic principles. The system is applicable to other metals, including bismuth, cadmium, cobalt, copper, manganese, mercury, and tin. A similar approach concerning the determination of thallium by electrophoresis has been reported, using an AISI smoke sampler set to sample for one hour with a space interval of 12 inches.[12] The authors of this paper reached similar conclusions regarding the potential usefulness of this technique.

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The Mortality from Sublethal Pulmonary Edema Superimposed upon Pneumoconiosis or Atelectasis

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Pulmonary edema was produced in normal rats by the injection of a dose of alpha naphthyl thiourea (ANTU) which killed 27% of the animals. The same dose of ANTU administered to rats handicapped by a reduced pulmonary reserve (oleothorax) or by pneumoconiosis resulted in a 60% mortality. This increased mortality rate supports the hypothesis (applied to smog deaths) that individuals with an appreciably reduced pulmonary reserve or with significant pneumoconiosis are more vulnerable to pulmonary edema-producing irritants than are normal individuals.

THE increase in the number of deaths that occur during periods of atmospheric inversion seem to involve individuals in the older age group. The common denominator to be found in the post mortem findings of these cases is pulmonary edema, generally associated with reduced pulmonary reserve and the presence of more than slight pneumoconiosis.

This suggests that people in the older age group with appreciable emphysema or considerable pneumoconiosis or both may be particularly vulnerable to a relatively small amount of pulmonary edema such as may be caused by an atmospheric pollutant.

In order to test this hypothesis, we designed the following investigation in which we determined the effect of sublethal doses of pulmonary edema upon animals handicapped either by a reduced pulmonary reserve or by pneumoconiosis.

Pulmonary Edema in Rats with Atelectasis

Method

Oleothorax was produced in 90 white rats by the injection of 10 ml mineral oil into the right side of the chest. This compressed the lungs and reduced the pulmonary reserve.

The LD_0 and LD_{50} of ANTU (alpha naphthyl thiourea) by intraperitoneal injection were determined on groups of stock rats. These values were found to be 6.4 mg/kg and 12.3 mg/kg respectively.

This investigation has been made possible by a grant from the American Iron and Steel Institute.

Two weeks after the production of the oleothorax, 30 of these handicapped animals were given what was considered to be an LD_0 of ANTU (6.4 mg/kg) and 30 others received the predetermined LD_{50} (12.3 mg/kg) of ANTU. The remaining 30 rats with oleothorax were not dosed and served as oleothorax controls. As additional controls, 30 normal rats of equal age and weight were also given 6.4 mg/kg ANTU and 30 other normal, similar animals were injected intraperitoneally with the supposed LD_{50} (12.3 mg/kg) ANTU.

In order to quantitate the degree of pulmonary compression produced by the oleothorax it became necessary to determine the inspiratory volume of the compressed lungs and of normal lungs as well as the volume of the respective chest cavities. For the purpose of obtaining these data, 10% formalin was injected intratracheally under pressure in 29 rats with oleothorax and in nine normal stock rats. The chest remained unopened although the skin was reflected to allow for better fixation of the chest wall. Prior to immersion of the entire animal in formalin, full strength formalin was injected into the abdomen to harden the viscera in situ. After the tissues were well hardened, the thoracic organs were removed *en bloc* and their volume was determined by displacement in mineral oil. The thoracic cavities were sponged dry and plaster-of-paris casts were prepared of them. These casts were dried in an oven and then impregnated with paraffin. Positive defects were removed and negative defects were filled in with wax. The volume of the casts was then determined by the dis-

placement of water. The data are given in Table II.

In order to determine the amount and percentage of edema fluid in the ANTU lungs it was necessary to obtain the moist and dry weights of the lungs as well as the body weight of the animal. The theoretical moist and dry weights of normal lungs from a normal animal of the same body weight were derived by means of constants. These data are given in Table III.

Results

With few exceptions, the rats died within 24 hours after the administration of ANTU. Three rats died on the second day and an additional five died at various intervals after this time. The former are included in the mortality data whereas the latter are not. The data are given in Table I.

It is interesting to note that although an approximate doubling of the dose of ANTU resulted in more than double the mortality rate in normal animals, in rats with oleothorax such increase in dosage had no effect upon the mortality rate. However, it is apparent that pulmonary compression more than doubled the mortality due to "minimal" edema.

In Table II are listed the average volumes of the thorax and its contents in normal rats and in animals with oleothorax. There is a 37% reduction in the ratio of the volume of thoracic content over the volume of the thoracic cavity.

The results of estimating the amount of edema fluid in the lungs are given in Table III.

It is seen that the differences in values between the groups are small. None of the differences between the various percentages in edema fluid is statistically significant.

TABLE I

ANTU Mortality

	No. of rats	Dose of ANTU mg/kg	No. of deaths in 48 hrs	Per cent mortality
LD_6 Control	30	6.4	8	27
LD_{16} Control	30	12.3	21	70
Oleothorax Control	30	—	0	0
LD_6 plus Oleothorax	30	6.4	19	63
LD_{16} plus Oleothorax	30	12.3	19	63

TABLE II

Mensuration of Lung Compression Due to Oleothorax

Group	No. of rats	Average volume of thoracic organs (A) ml	Average volume of thorax (B) ml	Ratio A/B	Per cent reduction in ratio A/B
Control	9	17.1 (9.8–19.9)	24.8 (12.2–31.2)	0.71 (0.60–0.82)	—
Oleothorax	29	10.7 (6.3–18.0)	24.3 (16.3–36.5)	0.44 (0.30–0.55)	37

TABLE III

Quantitation of Pulmonary Edema Following ANTU

Group	Average weight of rats gm	Average weight of normal lungs gm		Average weight of edematous lungs gm		Edema fluid	
		Moist*	Dry†	Moist	Dry	gm.‡	%§
LD_{77} ANTU Control	316	2.50	0.515	4.01	0.73	1.30	52
LD_{70} ANTU Control	316	2.50	0.515	3.70	0.69	1.03	41
Oleothorax plus LD_{77} ANTU	304	2.40	0.487	4.32	0.85	1.56	65
Oleothorax plus LD_{70} ANTU	304	2.40	0.487	3.86	0.80	1.15	48

* Normal lung weight (moist) = 0.0079 times the body weight. (Constant from Spector's Handbook of Biologic Data.)

† Normal lung weight (dry) = 0.206 times normal moist lung weight. (Constant derived from our own observations.)

‡ Edema fluid = Total fluid in edematous lung minus total fluid in normal lung.

§ Per cent edema = Amount of edema fluid ÷ average normal moist lung weight.

Pulmonary Edema in Rats with Pneumoconiosis

Method

Two series of 90 rats each received intratracheal injections of dust at about one-month intervals. The dose was 25 mg and the cumulative total, 150 mg. One series received quartz dust with an average particle size of 2.4 microns, whereas the other series was given kaolin dust with an average particle size of 2.3 microns.

Each series was divided into three groups of 30 rats each. One group in each series remained

TABLE IV

Mortality from ANTU in Pneumoconiotic Rats

Group	Quartz control (No ANTU)	LD_{77} ANTU quartz	LD_{70} ANTU quartz	Kaolin control (No ANTU)	LD_{77} ANTU kaolin	LD_{70} ANTU kaolin
No. of rats observed or dosed	14	13	20	26	28	26
No. of rats died	1	8	12	0	18	18
Per cent mortality	7	62	60	0	64	69

as a control whereas the other two groups received ANTU; one, the LD_{27} and the other, the LD_{70}.

Results

The cumulative spontaneous mortality in the quartz series amounted to 48%, nearly three-fourths of which occurred in the three weeks preceding the ANTU injections. The deaths were due to massive, confluent silicotic involvement which left insufficient lung tissue capable of function. There was usually a superimposed minimal pneumonia.

The cumulative spontaneous mortality in the kaoline series prior to the administration of ANTU was only 11%.

The mortality data following the intraperitoneal injections of ANTU are listed in Table IV.

Comment

If attention is focused upon the results obtained with the smaller dose of ANTU in rats with compression atelectasis of the lungs and in rats with either silicosis or kaolinosis; it is seen that the mortality which, in normal rats, is only 27% becomes about 60% in these handicapped animals.

Thus, there is here support for the hypothesis that an individual having a significant ventilatory handicap or dust deposits may die of a sublethal amount of pulmonary edema.

The mechanism of this death is, as yet, undetermined. Several possibilities come to mind. Both involve the concept of a vicious circle in which the initiation of pulmonary edema in the presence of certain handicaps causes the production of ever increasing amounts of such edema, leading to death. In the case of lungs that are handicapped by reduced ventilatory activity, Drinker's concept[1] is applicable.

According to Drinker[1] the alveolar capillary endothelium loses its semipermeability and becomes permeable in the presence of hypoxia. The capillary blood in compressed alveoli or in the air spaces of an emphysematous region tends to be under reduced oxygen tension. When, in addition to this deficiency, a layer of edema fluid upon the respiratory membrane impedes gaseous exchange, the hypoxia increases, causes more edema which increases the hypoxia still more.

In the case of a lung with pneumoconiosis, one must reckon with the mobilizing effect of pulmonary edema upon dust deposits to cause a redistribution and dispersion of the dust particle.[2] The liberation of innumerable fine dust particles and their irritation of the alveolar surface causes more edema[3] which, in turn, tends to liberate more sequestered dust.

The failure of the larger dose of ANTU to increase the mortality rate of animals with lung compression or with pulmonary dust deposits is not known. The amount of pulmonary edema is not increased with the larger dose of ANTU. This raises the question whether or not there is a proportionality between ANTU dosage and the amount of edema fluid in the lungs of normal animals.

Summary

Two types of pulmonary handicaps were produced in rats. In one series, intrapleural injections of mineral oil caused pulmonary compression. In another series of rats, the lungs were loaded with either quartz or kaolin dust by a sequence of monthly intratracheal injections.

With the exception of necessary controls, these animals were given intraperitoneal injections of ANTU (alpha naphthyl thiourea) which causes pulmonary edema. One-half of the animals were given 6.4 mg/kg and the rest were given 12.3 mg/kg.

The smaller dose of ANTU killed 27% of normal animals and approximately 60% of the handicapped rats regardless of the nature of the pulmonary handicap. This increased mortality rate supports the hypothesis that individuals with emphysema or other ventilatory defects or with significant pneumoconiosis are more vulnerable to pulmonary irritants that tend to produce pulmonary edema.

The larger dose of ANTU killed between 60% and 70% of normal rats as well as of the handicapped animals, also without regard to the nature of the pulmonary handicap. The reasons for the latter results are not known.

References

1. Drinker, C K.: *Pulmonary Edema and Inflammation.* Harvard University Press, Cambridge, Mass. (1945).
2. Gross, P., and J. H. U. Brown: The Mobility of Pneumoconiotic Deposits. *Am. J. Clin. Path. 22: 821* (1952).
3. Gross, P.: Biologic Testing of New Materials of Fine Particle Size. *Transactions of 19th Annual Meeting of Industrial Hygiene Foundation Transactions Bulletin No. 28* (1954).

Nine Years Experience with the Davis Halide Meter

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Although the Davis Halide Meter is one of the best portable instruments so far encountered for the evaluation of health hazards which may result from the inhalation of organic chloride vapors, it has not been completely free of difficulties. These problems are described along with corrective measures which have been developed. A partial list of items considered includes: effect of water vapor, inability to zero the instrument, effect of slit width, effects of high concentrations of organic halide vapors upon subsequent use and required calibration.

WE have used several Davis Halide Meters over a period of years and have found them to be the most useful portable instrument we have encountered for the evaluation of health hazards which may result from inhaling vapors of chlorinated organic materials. Experience gathered from the continued use of an instrument leads to changes and improvements over the original. The Davis Halide Meter, of course, is no exception since there have already been several modifications made.

Our first attempt to check the calibration of the Davis Halide Meter revealed a discrepancy between our calibration curve and that furnished with the instrument (Figure 1).

By varying the humidity of the air in the contaminated streams, (Curve B) we were able to almost reproduce the curve which was furnished to us (Curve C). Since we had no control of the humidity of the air when sampling in the plant, we decided to use a drying tube (Curve A) during both the calibration and the use of the instrument. Experimentation showed us that the response time of the instrument was lengthened by the use of the drying tube if enough Drierite were used to make frequent changes unnecessary. We arrived at a compromise which gives us a delayed response but also gives us reproducible results. A polyethylene drying tube 6 inches in length and 9/16 inch in diameter, was found to be about optimum when filled with fresh indicating Drierite. The Drierite must be changed as soon as its color turns from blue to red.

In our Davis Halide Meter we found what appeared to be considerable instrument noise—that is, rather sudden fluctuations of one to five microamperes. Also we found that the instrument reading would drift downscale so that rezeroing at about 30-minute intervals was required. The frequent re-zeroing posed a problem because we found that the charcoal filter was likely to become saturated and there was no ready means of knowing when this had occurred. It became necessary, therefore, to carry the instrument to an area where the atmosphere was thought to be uncontaminated whenever it was time for re-zeroing.

Continued experience showed repeated inability to zero the instrument either with the key up or with the key down. We found that this frequently was related to battery failure; not a serious matter since batteries could be replaced. Sometimes it was found that the cause was a deposit of solid material on the shutter plates. This too could be corrected in the field. Also, sometimes the shutter plates themselves had been moved too close together, either by someone not entirely acquainted with the instrument, or we think perhaps, by vibrations which occurred while carrying the instrument from one place to another. This was a serious matter since the calibration was changed by changing the slit width (Figure 2).

Figure 2 shows a comparison of methyl chloroform calibration curves for the same meter before and after the slit was adjusted. The industrial hygiene standard for methyl chloroform is 500 parts per million. The advantages of using calibration Curve B (Figure 2) are apparent.

The most serious cause of inability to zero the instrument was that the characteristics of the electrometer tube would change, and this required a replacement of the tube and subsequent recalibration of the instrument.

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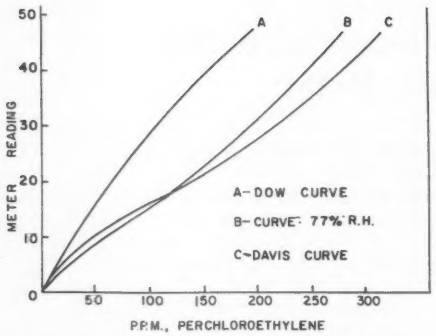

FIGURE 1. Comparison of calibration curves obtained at Dow with that supplied with the instruments. Also showing the effects of relative humidity.

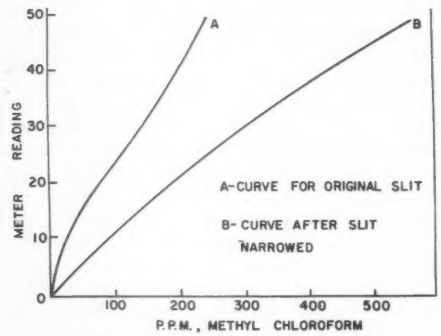

FIGURE 2. Comparison of methyl chloroform calibration curves with original setting of the slit and after readjustment to a narrower slit.

We established a policy of checking at least one point on the calibration curve of the instrument before and after each use. Changes in the response of the instrument were thus revealed. Several causes for increased or reduced sensitivity were found; most of them were related to mechanical (as opposed to electrical) parts of the meter. Reduced sensitivity was frequently associated with dirt on the blue glass filter or on the photo tube itself. This dirt was usually a dusty material which accumulated quite rapidly when the meter was used in relatively high concentrations of chlorinated materials. Sometimes reduced sensitivity was due to a build-up of a deposit on the shutter plates. This deposit was apparently similar to the dust on the filters and photo tube. A poorly spaced or poorly centered spark gap could result in either reduced or increased sensitivity depending upon the variation. Increased sensitivity resulted from an increased slit width caused by movement of the shutter plates, increased arc length and from cracked blue filters. It was found that the variability of readings at uniform concentrations could be due not only to circuit noise but also to impingement of air on the arc itself causing the arc to move back and forth. This arc movement was most important if the width of the slit were variable because of either pitting of the shutter plates or build-up of solid material on the plates. Other causes of variations in sensitivity and stability were found to be marked fluctuations in line voltage or air flow, or decided differences in shape and size of the copper electrodes.

As can be seen from Table I, the surprising increase or decrease of the microammeter reading corresponding to variations of the voltage represents errors of appreciable magnitude.

Analysis of the data in Table II indicates that changing electrodes seems to have an appreciable effect on the calibration of either meter.

Several changes have been made in an attempt to circumvent the above difficulties. The original electrometer tube bridge circuit has been replaced with an impedence matching device consisting of a high negative feed-back DC amplifier with a gain of essentially unity having a low impedence cathode follower output.

TABLE I

Effect of Voltage Changes on Response of Davis Meter to 100 Parts Per Million of Methyl Chloride

Voltage	Microammeter reading	Corresponding CH_3Cl concentration
120	7.5	90
115	8	102
110	9	140
100	12	190
95	(arc failure)	

TABLE II

Effect of Changing Copper Electrodes on Response of Davis Meters to 164 Parts per Million, Perchloroethylene

Electrode	Microammeter reading	
	Modified meter	Davis meter
No. 1	16	32
No. 2	26	41
No. 3	29	36
No. 4	—	39

Also included is a "bucking voltage" to compensate for incident light from the arc when no halogen is present. A DC power supply furnishes the B+ voltage for the photo tube as well as for the amplifier. This amplifier occupies the original tool chest compartment. Access to the battery compartment is achieved in the same manner as before. A receptacle is located in the amplifier for attaching an external recorder. The "zero key up" knob and the "zero key down" knob have been replaced by "background adjust" and "zero" knobs respectively. These knobs control the two helipots which now afford a greater range for balancing the circuit. The "background adjust" helipot is equipped with a scale; the "zero" helipot is not.

Noise of this modified circuit corresponds to variations no greater than one millivolt. The sensitivity of the circuit is not dependent upon tube characteristics as in the past. Longer tube life is achieved by operating a standard G.E. 12BE6 tube at a reduced filament voltage as the electrometer tube. This tube is inexpensive and is easily obtained from almost any radio or TV store. Changing this tube has had no effect on calibration. The regulated DC power supply which furnishes the B+ for the photo tube eliminates the necessity for a 67½-volt radio battery. Mercury batteries are used to furnish the bucking voltage and, as the current used is very small, the life expectancy of the batteries approximates shelf life. Also, a failure of these batteries does not show itself as a gradual deterioration of performance but rather as a sudden inability to operate the instrument.

We have recently begun using a fixed slit which is simply a saw cut in a piece of silicone laminate (Figure 3). In addition to eliminating slit-width variations and attendant difficulties, changing to this type of slit has resulted in three additional benefits. We no longer have any problem of the arc short-circuiting to, and consequently pitting, the shutter plates. Also, much to our surprise, the deposits of material on the slit which had been somewhat troublesome previously, no longer occurred. Therefore, impingement of air upon the arc was no longer a problem. What we need now is some way to prevent the deposit of dust upon the filter and the photo tube.

In our use of the Davis Halide Meter, we have found that the air sampling system should be checked each time the instrument is used by blocking the end of the sample tube and observing the consequent drop in flow from the optimum, as indicated by the rotameter, to zero. This constitutes a check against possible leaks due to line breakage or pump failure.

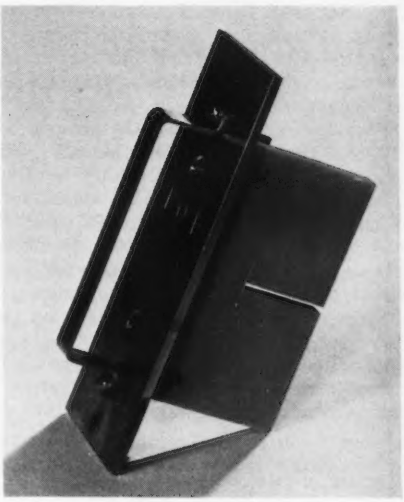

FIGURE 3. Fixed slit consisting of a simple saw cut in a piece of silicone laminate.

If the instrument fails to maintain the zero setting because of fluctuations in line voltage, a voltage regulator must be used between the instrument and the line.

Assurance that the meters are functioning properly and that the calibration curve is reliable are outstanding features of the modified meters. The amplifier circuit and the batteries are easily checked to assure proper operating conditions by measuring the "sensitivity" of the circuit. This is done by determining the number of scale divisions on the "background adjust" knob that correspond to a deflection of 10 units on the microammeter. If there has been no significant change from the originally measured sensitivity, proper performance of the amplifier and of the bucking voltage system is assured. If the "sensitivity" *has* changed appreciably, the meter requires the professional attention of an instrument man.

Difficulties in the mechanical portion of the instrument may be signaled by variations of the "background reading." The so-called "background" can be determined from the microammeter reading. It is actually the bucking voltage required to balance out the arc light with no halogen present. This background is found by first zeroing the meter with the "background adjust" and "zero" knobs with the arc chamber door open and the arc, therefore, off. The arc is then started by closing the arc chamber door. The resulting reading on the microammeter is recorded as "background." If this figure changes

appreciably from the background determined at the time of calibration, it probably means that the arc has either been changed in length or that it has been changed with relation to the slit, that the slit width has been changed, that the filter windows are dirty, that the photo tube is dirty, or that the charcoal filter has failed while checking for drift. If it is necessary to replace the copper electrode because of instability in the meter reading, a replacement should be chosen which is comparable in size. If the new electrode causes no more than "normal" variations of the original "background reading" it can be assumed that the calibration was not affected.

During the calibration procedure, the instrument is "zeroed" while in normal operation on halogen-free air. The "background adjust" dial reading is recorded and noted as the "zero setting." If, in the future, the instrument reads zero at this same setting, one can be assured that an atmosphere free of chlorides is being sampled and that the instrument has had sufficient "warm-up" time.

During the past two years, minor adjustments to the electrometer circuit have been necessary for only two meters out of the many in our possession. Therefore, the greater stability and durability of the electrometer circuit, coupled with the fact that the operators of the meter can themselves pinpoint and alleviate most difficulties encountered with the provided assurance that the calibration has not been disturbed, leads us to believe that the instrument is an extremely helpful and truly reliable analytical tool for the evaluation of health hazards.

National Goals in Air Pollution Research

AIR POLLUTION CONTROL is a subject of considerable interest to most of our readers, therefore all will be interested in the report of the Surgeon General's Ad Hoc Task Group on Air Pollution Research Goals. This report, *National Goals in Air Pollution Research*, Public Health Service Publication No. 804, may be purchased from the U.S. Government Printing Office, Washington, D.C.

This report outlines specifically the Task Group's conclusions as to: (a) the identification of national goals for air pollution research; (b) the cost of such research; and (c) the recommended allocations of financial responsibility among the Federal Government, States and local governments, and industry, for the several aspects of such research. In considering the total research effort needed, the Task Group identified ten principal goals for detailed consideration: (1) Effects on Man, (2) Agricultural Effects, (3) Economic Losses Due to Damage to Materials, Soiling, and Reduced Visibility, (4) Measurement and Identification, (5) Meteorology, (6) Atmospheric Reactions, (7) Surveys and Monitoring, (8) Control, (9) Information, Education and Training, and (10) Administrative and Legal Aspects. In total, the recommendations call for about a threefold progressive increase in nationwide air pollution research effort from the current estimated level of about $11 million annually to approximately $32 million by 1968. Of this maximal annual expenditure, about 40% is considered to be the responsibility of the Federal Government, 28% the responsibility of industry, and 32% the responsibility of State and local governments. Recommendations are made for the implementation of such an expanded program.

Parameters of Aerometric Measurements for Air Pollution Research

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A brief description of a continuous gas sampling network is presented in which a number of air pollutants is to be measured in six United States cities beginning about mid 1961. Parameters are presented of aerometric measurements from a two year study of sulfur dioxide in Louisville, Kentucky, to be related to health and other effects. Six equations are developed to depict the frequency, duration, and air pollution dosage.

AT what concentrations do air pollutants produce adverse effects? Of what significance are peak values or distributions of values for given averaging periods? Is dosage, above certain levels, that is, the integration of time-concentration relationships, a more desirable measure of pollution? Answers to these and similar questions asked by physicians, plant physiologists, engineers, and other scientists conducting research in air pollution are required in order to make optimum use of the information secured from aerometric monitoring programs.

Continuous Gas Sampling Network

A new project to be inaugurated this year by the Public Health Service is to measure continuously a number of pollutants in six cities and to analyze the data in a manner that will provide information relating the results to health and other effects. These pollutants include carbon monoxide, total oxidant, total hydrocarbons, nitric oxide, nitrogen dioxide, sulfur dioxide, and perhaps sulfur trioxide. Full scale operation of this program is scheduled for about summer of 1961.

To study reasonably short durations of high concentration, five-minute means are presently planned, resulting in some 10,000 measurements per day. These will be punched automatically on a 16-channel paper tape and forwarded to the Robert A. Taft Sanitary Engineering Center in Cincinnati for validating and analysis by means of an electronic computer and other modern automatic data processing equipment. The types of analyses to be performed are still tentative but those outlined below are under consideration.

An Air Quality Analysis of Sulfur Dioxide

To provide information on mean and peak concentrations and the frequency and duration of peak values of various levels of sulfur dioxide in Louisville, Kentucky, charts representing two years of continuous sulfur dioxide monitoring at a station in that city were analyzed in detail. These results are presented here as illustrative of this type of study and analysis.

Frequency Distributions

Frequency distributions of the durations of various sulfur dioxide levels (200, 300, 400, 500, and 1000 ppb) were determined and tabulated by month, season, year, and total for a 23-month period in the years 1956 and 1957. Table I presents detailed data for the 200 ppb level. Table II presents the 2-year totals for the other levels. They provide information on questions such as the following: "How many times during 1956 did the sulfur dioxide concentration exceed 200 ppb for 2.0 or 2.1 hours?" The answer is six (Table I).

Cumulative distributions of frequency of duration have been calculated and plotted (Figure 1) for 1956 and 1957 for each of the five selected sulfur dioxide levels. The points tend to form straight lines when plotted on log-probability paper, indicating an approximately log-normal distribution with a standard geometric deviation of five. The point where each line intersects the fifty percentile has been determined and plotted against the concentration (Figure 2), using logarithmic paper. Since the data tend to approximate a straight line, the median duration of the occurrence of a given sulfur dioxide level can be expressed by the following equation:

$$D_{\text{med}} = \frac{1.5 \text{ minutes}}{(\text{ppm } SO_2)} \qquad (1)$$

where D_{med} is the median duration of an occurrence, and the concentration of SO_2 is expressed in ppm.

TABLE I

Frequency and Duration of Periods during which the SO_2 Concentration Exceeded 200 Parts per Billion in 1956 and 1957

(Periods are grouped in two tenths of an hour intervals with upper limit shown.)

Time Covered	DURATION OF PERIODS IN HOURS																													Summary of Data For Occur. of SO_2 Concs. Greater than 200 PPB		
	.1	.3	.5	.7	.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	Greater than 6 Hrs.	Mean Dur. (Hrs.)	Total Dur. (Hrs.)	No. of Occur.
56 & 57 (Dec. 56 missing)	340	116	52	35	6	15	16	10	7	3	9	3	2	2	1	7	1	1	1		2	1	3	1		1	1				6	0.52	349.5	674
56	191	84	31	25	7	12	8	4	5	3	6	1	1	1		5	1	1			1		3	1		1					1	0.49	191.5	393
WIN	43	16	9	6		1	2	1	4	2	3	1				1	1						3	1		1						0.72	66.7	93
JAN	27	12	6	4			1	1	3	1	1						1						2	1		1						44.1	61
FEB	16	4	3	2		1	1		1	1	2	1				1							1									24.6	34
SPR	67	27	10	7	1	7	2	1	1	1	3			1		2					1										1	0.47	62.7	132
MAR	24	19	6	3	1	3	2	1	1	1	2																					26.1	63
APR	20	1	2	1		2					1																					5.0	27
MAY	23	7	2	3		2								1		2					1										1	28.5	42
SUM	40	19	5	5	5	1		1																								0.28	21.0	76
JUN	14	3	1	2	1																												4.8	21
JUL	18	5	3	2	1	1																											7.5	28
AUG	10	11	1	1	3			1																									9.7	27
FAL	41	22	7	7	1	3	4	1					1			2		1														0.43	39.1	90
SEP	11	2	2										1			1																	8.4	20
OCT	12	7	2	3	1	2												1															12.0	26
NOV	15	13	3	4		1	4	1								1																	10.7	42
57	149	62	21	10	1	3	8	6	2		3	2	1	1	1	2			1		1	1					1				5	0.50	157.0	281
WIN	40	24	6	2	1		5	2	1		3		1		1	1					1	1					1				2	0.78	71.9	92
DEC	2	1																															.4	3
JAN	22	15	6	1	1		3	1	1		2					1						1											27.9	54
FEB	16	8		1			2	1			1		1		1												1				2		43.6	35
SPR	50	13	5	3		3		1	1			1				1															1	0.41	32.6	79
MAR	7	3		3		3		1				1				1															1		22.2	28
APR	27	5	2																														4.9	34
MAY	16	5	3						1																								5.5	25
SUM	45	20	8	5			2	3																								0.28	22.6	83
JUN	23	13	6	2			2	2																									14.0	48
JUL	18	6		2				1																									5.8	27
AUG	4	1	2	1																													2.2	8
FAL	14	5	2				1					1		1					1												2	1.10	29.7	27
SEP	8	3	1				1																										3.2	13
OCT	3	1																															.6	4
NOV	3	1	1									1		1					1												2		25.9	10

The mean durations of occurrences of given sulfur dioxide levels have been plotted on logarithmic paper (Figure 2). They also approximate a straight line, which can be expressed as follows:

$$D_{ave} = \frac{6 \text{ minutes}}{(\text{ppm } SO_2)} \tag{2}$$

where D_{ave} is the mean duration of an occurrence.

The "number of occurrences" and "total time a given level is exceeded" have been plotted logarithmically (Figure 3). Since the data plot as approximately straight lines, the relationship (reduced to a yearly basis from the 23-month basis shown in the figures) may be expressed as Equations 3 and 4.

$$\frac{N}{\text{yr}} = \frac{20}{(\text{ppm } SO_2)^2} \tag{3}$$

$$\frac{T_{tot}}{\text{yr}} = \frac{2 \text{ hours}}{(\text{ppm } SO_2)^3} \tag{4}$$

where N is the number of occurrences, and T_{tot} is the total time which a given concentration was exceeded.

An arithmetic normal frequency distribution may be expressed as follows:

$$f(x) = \frac{\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]}{\sqrt{2\pi}} \tag{5}$$

Since the sulfur dioxide data appear to be log-normally distributed, the distributions may be expressed as follows:

$$f(x) = \frac{\exp\left\{-\frac{1}{2}\left[\frac{\ln D - \ln\left(\frac{1.5}{\text{ppm}}\right)}{\ln \sigma_{geo}}\right]^2\right\}}{\sqrt{2\pi}} \tag{6}$$

where ln D is the natural logarithm of the duration, the concentration is expressed in ppm, and σ_{geo} is the standard geometric deviation.

Substituting 5 for the standard geometric deviation as developed previously (Figure 1), and simplifying, gives

$$f(x) = \frac{0.40}{\exp\{0.193[\ln D - 0.40 - \ln(\text{ppm})]^2\}} \tag{7}$$

Equation 7 represents the family of lines plotted on Figure 1.

TABLE II

Frequency and Duration of Periods during which the SO_2 Concentration Exceeded 300, 400, 500, and 1,000 Parts per Billion in 1956 and 1957—Totals for the Two Years.

Duration* hours	Number of Occurrences				Duration* hours
	300	400	500	1,000*	
.1	222	151	108	5	.01
.3	62	18	13	10	.03
.5	20	12	10	3	.05
.7	13	7	2	8	.07
.9	5	2	2	4	.09
1.1	6	3		2	.11
1.3	1	1		1	.13
1.5	2	1	2		.15
1.7	2	2	1		.17
1.9	2				.19
2.1				1	.21
2.3	1	1		1	.23
2.5	3				.25
2.7	1		1		.27
2.9		1			.29
3.1	3			1	.31
3.3					.33
3.5					.35
3.7					.37
3.9				1	.39
4.1	1				.41
4.3					.43
4.5					.45
4.7					.47
4.9					.49
5.1	1				.51
5.3					.53
5.5		1			.55
5.7					.57
5.9					.59
>6.	1				>.6
Total No.	346	200	139	37	Total No.
Mean duration hours	0.33	0.25	0.21	0.073	Mean duration hours
Total duration hours	114.5	50.7	28.7	2.69	Total duration hours

* Periods are grouped in intervals of 0.2 hr except for 1,000 ppb where the interval is 0.02 hr.

(Note: Dec. 1956 missing in all summaries.)

Equations 3 and 7 are useful for predicting the relationship between frequency of occurrence, concentration, and duration of an occurrence. Curves have been computed for various frequencies of occurrence and plotted (Figure 4). Figure 4 is useful for answering questions such as: "What is the maximum time, expected once per month, that the sulfur dioxide concentration will remain above 1 ppm?" The answer is two minutes. Similarly for other frequencies: An 8-minute duration above the 1 ppm level is expected to occur four times per year; and a 60 minute duration once in five years. It is noted that Figure 4 indicates only that the expected concentration is above a specified value, and *not* the amount the expected concentration exceeds this value.

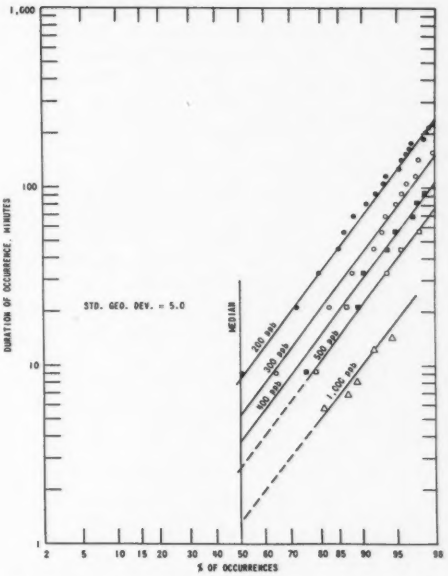

FIGURE 1. Frequency of varying duration occurrences which exceeded various levels of SO_2 during 1956 and 1957.

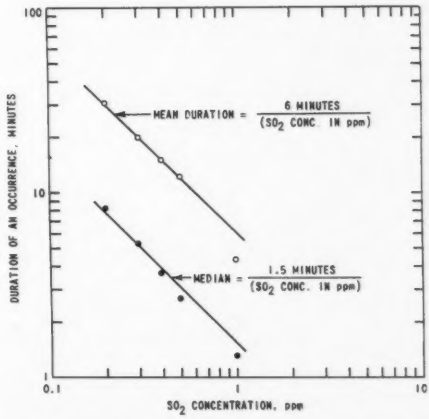

FIGURE 2. Mean and median durations of SO_2 occurrences which exceeded various levels during 1956 and 1957.

Air Pollution Dosage

Detailed data from a continuous pollutant concentration chart are useful in determining

total dosage due to individual air pollutant occurrences. From such a chart, the total dosage above any specified threshold level may be determined as the area between the concentration curve and the specified threshold level.

The total air pollution dosage for a given period of time above any threshold level also may be determined. For instance, for a one year period, Equation 4 may be integrated to yield Equation 8. It is pointed out, however, that this dosage is not continuous in time, but the summation of

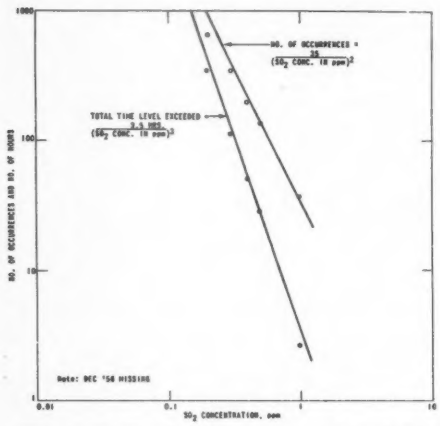
NO. OF OCCURRENCES AND NO. OF HOURS
NO. OF OCCURRENCES = 35 / (SO2 CONC. IN ppm)^2
TOTAL TIME LEVEL EXCEEDED = 3.5 HRS. / (SO2 CONC. IN ppm)^2
Note: DEC '56 MISSING
SO2 CONCENTRATION, ppm

FIGURE 3. Number of occurrences and total number of hours during which the SO_2 concentration exceeded various levels during 1956 and 1957.

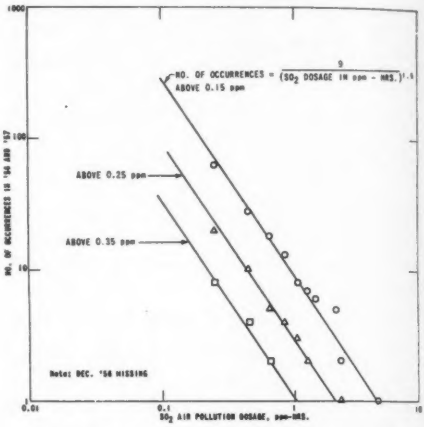
NO. OF OCCURRENCES IN '56 AND '57
NO. OF OCCURRENCES = 9 / (SO2 DOSAGE IN ppm - HRS.)^1.5
ABOVE 0.15 ppm
ABOVE 0.25 ppm
ABOVE 0.35 ppm
Note: DEC. '56 MISSING
SO2 AIR POLLUTION DOSAGE, ppm-HRS.

FIGURE 5. Number of days of 1956 and 1957 on which the SO_2 air pollution dosage reached stated amounts.

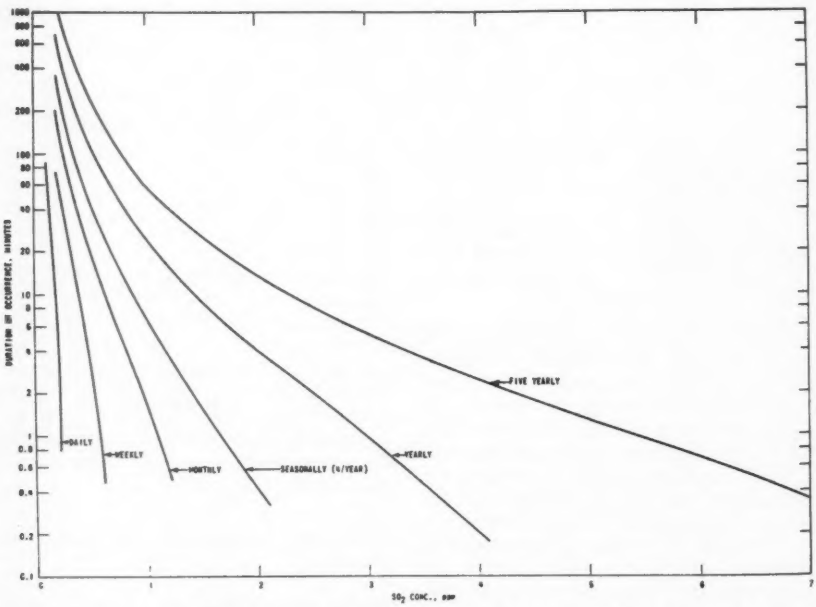

FIGURE 4. Predicted frequency of maximum expected durations of SO_2 occurrences above given levels.

many individual doses above the threshold limit for the selected time period.

$$\frac{\text{Dose}}{\text{yr}} = \frac{1 \text{ ppm} - \text{hr}}{C_{th}^2} \quad (8)$$

where Dose is the total air pollution dosage, and C_{th} is the threshold concentration expressed in ppm.

Substitution in Equation 8, for instance, indicates that the total air pollution dosage above 0.25 ppm for one year is 16 ppm-hr. Equation 8 should not be used in this example for threshold concentrations less than 0.2 ppm, the lower limit of concentration explored in this study.

Daily sulfur dioxide dosage frequencies above threshold levels 0.15, 0.25, and 0.35 ppm were calculated and plotted (Figure 5). Figure 5 is useful for answering questions such as, "On how many days of the 23-month period during 1956 and 1957 did the air pollution dosage above 0.25 ppm exceed 1 ppm-hr?" The answer is 3.

The curves depicted on Figure 5 (reduced to 12/23 to represent an annual value rather than a 23-month period) are expressed by Equation 9.

$$\frac{SO_2 \text{ days}}{\text{yr}} = \frac{24}{e^{11 C_{th}} (SO_2 \text{ ppm} - \text{hr})^{1.5}} \quad (9)$$

where SO_2 days is the number of days on which a given SO_2 air pollution dosage is reached, and the SO_2 dosage is expressed in ppm-hours.

The equations developed represent the yearly sulfur dioxide pattern. Similar techniques could be used to express seasonal patterns. For instance, Table 1 indicates that the sulfur dioxide concentration exceeds 200 ppb during three times as many hours in the winter as in the summer.

Problem Solutions

As an example of how the basic equations might be used, they are here applied to specific problems:

First, consider peak sulfur dioxide occurrences above the taste threshold of 0.3 ppm: 220 such occurrences are expected per year (Equation 3); the mean duration of an occurrence is 20 minutes (Equation 2); the median duration is 5 minutes (Equation 1); the total time the concentration is expected to be above 0.3 ppm is 74 hours per year (Equation 4); the total annual air pollution dosage expected above 0.3 ppm is 11 ppm-hr (Equation 8); and the maximum duration of an occurrence above 0.3 ppm expected once per week is 20 minutes (Figure 4), that expected once per months is 80 minutes, and once per year 300 minutes. The answer to the question "How many days per year is the concentration expected to remain above 0.3 ppm such that the total dosage will equal 0.2 ppm-hr?" is 10 times per year (Equation 9).

Consider next peak sulfur dioxide occurrences above 0.5 ppm: 80 such occurrences are expected per year (Equation 3); the mean duration is 12 minutes (Equation 2); the median duration is 3 minutes (Equation 1); the total time the concentration is expected to be above 0.5 ppm is 16 hours per year (Equation 4); the total air pollution dosage per year expected above 0.5 ppm is 4 ppm-hr (Equation 8); and the maximum duration of an occurrence above 0.5 ppm expected once per week is 3 minutes (Figure 4), expected once per month is 20 minutes and once per year 120 minutes. The answer to the question "How frequently is 0.1 ppm-hr of dosage above 0.5 ppm expected?" is 2 times per year (Equation 9).

Summary of Equations

Analysis of 23 months of continuous sulfur dioxide concentration data indicates that the characteristics of sulfur dioxide occurrences in Louisville may be depicted approximately by the following equations:

$$\frac{N}{\text{yr}} = \frac{20}{(\text{ppm } SO_2)^2}$$

$$D_{ave} = \frac{6 \text{ minutes}}{(\text{ppm } SO_2)}$$

$$D_{med} = \frac{1.5 \text{ minutes}}{(\text{ppm } SO_2)}$$

$$\frac{T_{tot}}{\text{yr}} = \frac{2 \text{ hours}}{(\text{ppm } SO_2)^3}$$

$$\frac{\text{Dose}}{\text{yr}} = \frac{1 \text{ ppm} - \text{hr}}{C_{th}^2}$$

$$\frac{SO_2 \text{ days}}{\text{yr}} = \frac{24}{e^{11 C_{th}} (SO_2 \text{ ppm} - \text{hr})^{1.5}}.$$

A Study of the Relation of Visibility to Air Pollution

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Attempts to determine a workable relationship between visibility and the soiling index of air sampling tapes are described. It is shown that visibility is a function of relative humidity, whereas soiling index is not. Albeit the visibility-soiling index-humidity correlations were significantly different from zero at a high level of confidence, they are not of such quality as to permit good quantitative estimates of soiling index from measurements of visibility and humidity. The reproducibility of soiling index within reasonable limits is questioned, since under nearly identical visibility and humidity conditions the soiling index values vary over a relatively wide range.

Introduction

IT is very desirable to have at hand a simple and reliable air pollution "index"; this index should be provided by measurements that can readily be made, following a minimum of instruction, by observers of widely diversified backgrounds. The determination of an index based upon measurements obtained by complex instrumentation is often economically unfeasible. Thus, it is highly desirable that the measurements required to compute the index be inexpensively obtained in order to permit widespread usage.

The effects of air pollution are numerous and varied and can be measured in many ways. The sensory effects are the most obvious since many of them are noted instantaneously upon their occurrence. Of these, the visibility parameter is the only one which may be assigned a quantitative value, and which may be compared quantitatively with similar observations.

The theoretical aspects of the reduction of visibility are well known.[1, 2, 3] It is in the application of theoretical knowledge to practical problems that difficulties arise. This is rather unfortunate since visibility is one of the best documented of the meteorological elements that are affected by atmospheric contamination. The air quality parameters against which visibility has been compared in the past have included the number[4] and mass[5] of particulates, and light transmission through[6] or reflectance from[7] filter mediums.

The objective of this study was to determine a relationship by which one individual observation of appropriate meteorological parameters, including the readily observed visibility measurement, may be used to give a reasonable quantitative estimate of air quality. Thus, it is important to point out that no attempt has been made to minimize the random errors in the data by means of any type of averaging procedure. The shortest possible time periods, based on available data, were used.

Physical Basis for a Visibility-Soiling Index Relationship

Following Neuberger,[2] the visual range, V', for average daytime conditions can be expressed as

$$V' = \frac{3.912}{\beta} \tag{1}$$

where V' is expressed in units of length. The attenuation coefficient, β, may be determined from the relationship

$$\frac{I}{I_0} = e^{-\beta L} \tag{2}$$

where I is the flux density measured at distance L from a source of light of any constant intensity through a *contaminated atmosphere*, and I_0 is the flux density measured at the same distance through a *purified* atmosphere. It follows then that the intensity of the light source itself does not have to be known. With these definitions, the logarithmic transformation of Equation 2 yields the optical density, D;

$$D = \log \frac{I_0}{I} \alpha \beta \cdot L \tag{3}$$

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which is a parameter indicating the light attenuating effects of the aerosol.

We shall assume that the light attenuation is due entirely to particulate matter which may be removed from the air by mechanical filtration. If the particles in the air throughout a column of length L are deposited on the filter, we can determine I_o in Equation 3 by measuring the light intensity through a clean portion of the filter and I by measuring the light intensity through the soiled portion. It is recognized that the optical density determined through the filter will differ from that determined through the natural atmosphere. However, in order to proceed further, the working hypothesis will be made that the respective optical densities are representative of one another, *i.e.*, the attenutation of light by the particles on the filter is representative of the attenuation of light by the particles in their free state.

The optical density is commonly determined via the filter tape method as an estimate of atmospheric pollution and is generally expressed in Coh units, a soiling index, defined by Hemeon *et al.*[5] as being equivalent to 100 D. To compensate for the characteristics of different samplers, the Coh units are then converted to Coh units per 1000 feet, which, for convenience, shall be referred to as C^*. The linear length, L, is determined by dividing the volume of air sampled through a given portion of the filter medium by the area of the filter through which the sample was drawn. Having arbitrarily set I_o in Equation 3 equal to unity in the evaluation of the tape (so that $\log I_o = 0$),

$$C^* = \frac{-10^3 \log I}{L}, \qquad (4)$$

which defines the air quality parameter that is used in this study.

The visual range, visibility, and prevailing visibility are not synonymous,[9] although they are often used interchangeably. Since the U. S. Weather Bureau normally records only the prevailing visibility, and since the theory is based upon visual range, another working hypothesis will be made: the prevailing visibility is representative of the visual range and shall be called simply the visibility, V. It is readily seen that V, substituted for V' in Equation 1, and C^* of Equation 4 are related through equation 3.

It is an established fact that particle size, and thus visibility, is a function of humidity.[1, 2] Orr *et al.*[10] have, by experimental analysis, verified the theoretical particle size-humidity relationships for certain hygroscopic and nonhygroscopic compounds in the sub-micron particle size range; however, the parameters that are required to solve these complex relationships are not readily determined except under rigidly controlled laboratory conditions. It follows that in general field work the theoretical visibility-humidity relationship must be replaced by a more utilitarian empirical relation. This was borne in mind throughout the study in the light of preliminary tests that showed visibility and C^* are not significantly related unless the humidity is considered.

Evaluation of Possible Sources of Error in C*

It was suggested during the early course of the study that the relative humidity might have an effect on the sampling tape at the time of sampling, thus resulting in erroneous values of C^*. Two AISI automatic smoke samplers supplied with Whatman No. 4 filter tape were run concurrently at the same location in Cincinnati; similar intake systems were provided except that the air going to one of the samplers was heated in order to lower the relative humidity. The differences noted in the C^* values thus obtained from the two samplers were not statistically significant. It was decided to also check the humidity effects at the time of analysis in the laboratory. An exposed tape with approximately 100 soiled spots was analyzed at laboratory humidities ranging from 15% to 100% and the differences noted were well within the error of the readings themselves.

The linear relationship between Coh and C^* holds true only when the ratio of I_o to I is less than about 2.0,[5] due probably to the reduction of flow rate through the filter as the particulates clog the filter. A correction factor for the reduction in flow rate has been suggested[11] but such corrections were not made to the C^* data used in this study.

Variations in the transmission of light through clean filter tape have been observed. These variations, which would result in errors in I_o, are not statistically significant as regards the mean value of the transmission. However, when this random and thus unpredictable error in the transmission is disregarded, the resultant C^* value can differ from the true C^* value by a considerable amount. A complete treatment of this source of error, which is magnified by way of the logarithmic transformation of I_o and I, will be presented at a later date following a more detailed evaluation of its effect on C^*.

A preliminary investigation was made of the C^* data obtained concurrently from two different samplers and tapes. The C^* values obtained from an AISI sampler supplied with Whatman No. 4 filter tape accounted for 39 per cent of the

variance of visual range, with a standard error of estimate of 2.24 mi.; an S.E.C. sampler[12] supplied with a special Millipore tape accounted for 59 per cent of the variance in visual range with the error of estimate being 1.84 mi. The C^* values obtained from the Whatman No. 4 filter tape were generally only about 50% of those obtained with the Millipore tape. Whatman tape consists of a mat of randomly interwoven fibers, and Millipore consists of a plane surface containing microscopic pores of uniform size resulting, apparently, in greater filter efficiency. The visibility was determined by converting readings of transmissivity from the U.S.W.B. transmissometer. As these results were derived from only 25 2-hour sampling periods, further investigation is certainly in order.

Data Sources

Data from observational periods during which precipitation occurred were excluded from the study because of its obvious effects on visual range. Periods during which fog was present were not excluded.

St. Louis, Missouri

St. Louis visibility observations were made visually by U. S. Weather Bureau personnel at the Federal Building. The observations, at 0600, 1200, and 1800 CST (Central Standard Time), fell about midway through each 3-hour air sampling period, the latter beginning daily at 0430, 1030 and 1630 CST. The AISI sampler, owned and operated by the City of St. Louis, was also located on the roof of the Federal Building.

Dry-bulb temperatures were available from the downtown Weather Bureau Office, and dew point temperatures were available from the Weather Bureau Office at Lambert Field, approximately 14 miles northwest of the city. Assuming the dew point temperature to be uniform and conservative, and thus the same at both locations, airport dew point temperatures and downtown dry-bulb temperatures were used to estimate the relative humidity at the downtown site for the time of the visibility observation.

Cincinnati, Ohio

The Cincinnati observations were taken at a location about 1 mile west of the downtown area, toward the southern end of an industrial area in the Mill Creek Valley. A U. S. Weather Bureau transmissometer at the site measures the transmissivity of the atmosphere at a height of 14 feet above the ground level. The AISI sampler was located nearby. The air sampler was set to obtain 2-hour samples, and the transmissivity was obtained by averaging (by equal-area method) the transmissometer record over the corresponding periods. Humidity data were obtained from a hygrothermograph exposed in a U.S.W.B. standard thermoshelter at the site.

The equipment was run continuously, but only selected periods of observation were used because of localized clouds of dense dust raised by construction equipment in the immediate vicinity of the site. Data were chosen only from non-working hours, which included evenings and nights on working days, and all observations over weekends.

Analytical Procedures and Results

The St. Louis data were analyzed in the manner indicated below in order to determine if a systematic relationship could be found between visual range and C^* holding the humidity relatively constant.

The data were divided into two main categories based upon degree days: (a) winter months, which were defined in general as the months of November through March, and (b) summer months, June through September; data from the remaining transitional months were not used in the study. These groupings were made because of the probability of seasonal changes in the physical characteristics of air-borne particulates. The data for each of the three previously mentioned observation times were treated separately to eliminate the effects of diurnal variations in the parameters.

All data were then stratified into humidity categories by 10% humidity intervals from 60 to 100%; humidities less than 60% were kept in one group within each season and time category. Neuberger[2] and others have shown that below "roughly" 70% humidity, the visual range is little affected by variations in humidity; a humidity of 60% was used as the cutoff value in this portion of the study to provide a margin of safety to the estimated value (70%) of the critical humidity.

Partial regression coefficients were then determined by the least squares method for the relationship

$$\log V_H = a + bC^* \tag{5}$$

where V_H is the visibility, with dimensions in miles (the subscript H merely indicates that this is a partial regression analysis, confined to groupings of humidity), and a and b are empirically determined constants.

A plot of the 1200 CST winter data for humidities less than 60%, along with the regression line determined from Equation 5, is shown in Figure

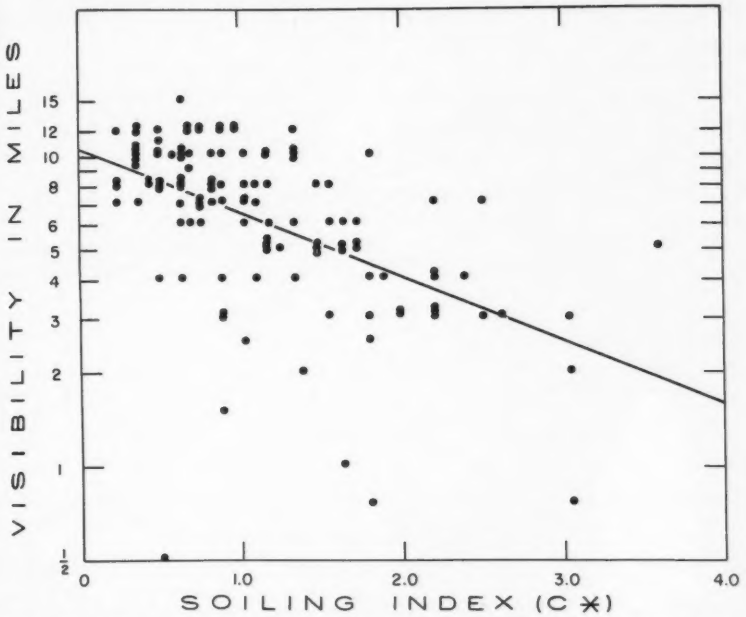

FIGURE 1. Log-law relationship of visibility and soiling index at 60% relative humidity. (1200 CST, winter, St. Louis).

1. The scatter of points for the other sets of data is not at variance with this figure. The regression lines for the humidity classes of the noontime winter data are shown in Figure 2 where, theoretically, the curves should: (a) be nearly parallel with one another, at least so as not to overlap within the range of C^* values encountered; (b) have a negative slope; and (c) be in numerical order by relative humidity, with less than 60% humidity at the top of the graph and 90–100% at the bottom. Criterion (a) does not hold for the majority of the sets of data tested; (b) holds true in most of the cases, and (c) is generally true, but only within the range of the mean C^* values encountered within a given season and time category.

In Figure 2, the number of observations, N, is indicated for each humidity group, and the circles are plotted at $(\log \bar{V}, \bar{C^*})$. The inconsistencies among the regression lines did not present a clear picture of the effect of humidity alone on visibility. Therefore, another approach was used. Curves of visibility on C^* at humidities less than 60%, as exemplified by the top curve in Figure 2, were used to determine a "calculated" visibility, V_{calc}, defined here as the probable visibility at humidities less than 60% for a given C^*. V_{calc} then, depends upon the value of C^* that was obtained during the period in which the observed visibility, V_{obs}, was determined. The differences between the logarithms of V_{calc} and V_{obs} were then plotted against the ambient relative humidity. This was done for the 0600 CST summer and the 1200 CST winter observations (Figure 3).

The results show that at constant C^* an increase in humidity from 60 to 100% causes the visibility to decrease by about 40% in summer at 0600 CST. In the winter at 1200 CST, for the same humidity increase, the visibility decreases by about 75%. The greater decrease in winter suggests that particles in winter are more hygroscopic than in summertime. The coefficient of correlation for the winter data is 0.57, and for the summer data, 0.30.

It was felt that the above analysis, using partial statistics, did not permit proper consideration of the important humidity variable; thus it was decided to examine the data in the form

$$V = c + d \cdot \log\ (C^* \cdot RH) \qquad (6)$$

where RH is the relative humidity in whole percent. Equation 6 is similar to an equation determined empirically after many trials some years ago[4] except that the number concentration of particles is replaced here by C^*. The results derived from using this equation for both the St.

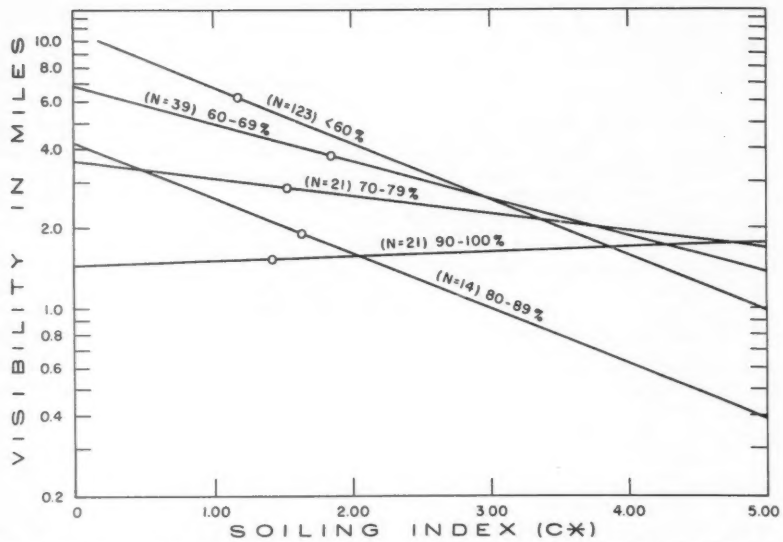

FIGURE 2. Summary of relationships of visibility and C*, by humidity classes. (1200 CST, winter, St. Louis)

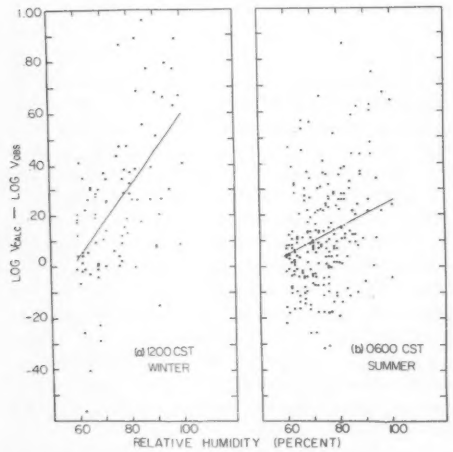

FIGURE 3. Differences between the logarithms of the calculated and observed visibilities vs humidity.

Louis and Cincinnati data are given in Table I. Statistics from the Cincinnati data were determined by replacing V with the transmissivity, T, of the atmosphere in decimal form. The resulting correlations indicate that the estimates of air quality determined via this form of relationship would not be reliable.

TABLE I

Statistics Derived from the Relationship
$V = c + d \cdot \log (C^* \cdot RH)$

(r is the simple correlation coefficient, s_e is the standard error of estimate of V about the line of regression, and N is the number of observations. Note that V has been replaced by the transmissivity, T, in decimal form, for the Cincinnati data.)

Cincinnati (Oct.–Nov. 1958)

	Resulting equation	r	s_e	N
Day...	$T = 1.067 - .059 \log (RH \cdot C^*)$	−.68	.034	79
Night..	$T = 1.112 - .082 \log (RH \cdot C^*)$	−.39	.082	213

St. Louis (1954–1957)

Heating	Resulting equation	r	s_e	N
0600...	$V = 11.30 - 3.78 \log (RH \cdot C^*)$	−.42	2.71	224
1200...	$V = 16.29 - 5.62 \log (RH \cdot C^*)$	−.53	3.55	230
1800...	$V = 13.50 - 3.41 \log (RH \cdot C^*)$	−.37	3.21	230
Non-heating				
0600...	$V = 10.69 - 2.87 \log (RH \cdot C^*)$	−.31	2.80	299
1200...	$V = 12.66 - 2.86 \log (RH \cdot C^*)$	−.35	2.63	301
1800...	$V = 11.63 - 1.97 \log (RH \cdot C^*)$	−.29	2.18	294

Further study led to another equation relating V, C^*, and humidity which was derived from theoretical and empirical considerations. A laconic description of the derivation is given below.

The attenuation coefficient, β, of Equation 1, may be replaced by an identity resulting in

$$V = \frac{3.912}{N\pi r^2 Q}, \tag{7}$$

where N is the number of particles of radius r and extinction efficiency Q. From Neiburger and Wurtelle,[13]

$$r_0(1 - H_0)^{1/3} = r(1 - H)^{1/3} \tag{8}$$

where r_0 is the particle radius at humidity H_0 (in decimal form), and r is that at H. Solving Equation 8 for r, after assigning a value of zero to H_0 (recalling that humidity has no effect on C^*), and substituting this into Equation 7 results in

$$V = \frac{3.912(1 - H)^{2/3}}{N\pi r_0^2 Q}. \tag{9}$$

Assuming Q does not change with particle size, we may then replace the denominator with the β corresponding to r_0. From Equations 4 and 3, it can be seen that $\beta \propto C^*$. Making these substitutions and combining the coefficients results in

$$V = \frac{32.17(1 - H)^{2/3}}{C^*}. \tag{10}$$

To test the equation the coefficient and exponents in the righthand term were relaxed; i.e., they were solved anew by applying common statistical methods to the data in the form

$$V = \frac{g(1 - H)^h}{C^{*i}} \tag{11}$$

An electronic computer multiple regression analysis provided estimates of g, h, and i, and also the statistics necessary for the computation of the multiple correlation coefficient. The results are compiled in Table II. Note that for the Cincinnati data, V has again been replaced by the transmissivity, T.

Discussion

It was shown that variations in the relative humidity at the time of sampling and of filter evaluation had no significant effect on the resulting C^* values. If it is true that the flow rate through the tape is an inverse function of humidity (as has been suggested), an error due to variations in humidity would be introduced into the resulting C^* values; should such an error exist, it is apparently either negligible or compensated for by some other source of error.

TABLE II

Statistics Derived from the Relationship $V = [g(1 - H)^h]/C^{*i}$

(R' is the multiple correlation coefficient, S_e the standard error of estimate of log V about the plane of regression, and N the number of observations. Note that V has been replaced by the transmissivity, T, in decimal form, for the Cincinnati data.)

Cincinnati (Oct.–Nov. 1958)

	Resulting equation	R'	S_e	N
Day...	$T = .978\ (1 - H)^{.012}\ C^{*-.020}$	.69	.011	79
Night..	$T = .783\ (1 - H)^{.026}\ C^{*-.027}$	.28	.061	213

St. Louis (1954–1958)

Heating	Resulting equation	R'	S_e	N
0600...	$V = 3.56\ (1 - H)^{.024}\ C^{*-.264}$	.30	.307	300
1200...	$V = 10.64\ (1 - H)^{.400}\ C^{*-.475}$	.62	.219	320
1800...	$V = 12.42\ (1 - H)^{.716}\ C^{*-.109}$	.63	.190	321
Non-heating				
0600...	$V = 8.75\ (1 - H)^{.496}\ C^{*-.240}$	.45	.232	397
1200...	$V = 9.48\ (1 - H)^{.322}\ C^{*-.129}$	.39	.134	405
1800...	$V = 9.51\ (1 - H)^{.172}\ C^{*-.057}$	.31	.110	393

There is no significant difference between the correlation of visibility and C^* using a sampling medium of Millipore tape and that using Whatman No. 4 tape. However, the test, for which limited data were available, warrants verification using a greater number of observations since the filtering efficiency of the millipore filter is apparently greater than that of the Whatman filter (C^* Millipore $>$ C^* Whatman), and conceivably should produce (statistically) better correlations in a study of this type.

The problem throughout the study was to explain the wide range of scatter of the data. Following the first attempt at determining the relationship it was assumed that the scatter was due to the fact that the proper form of relationship had not been used, or that the simplifying assumptions were not valid. As the study progressed, and various relationships were tested, it appeared that some other factor or factors must be responsible for the scatter.

In retracing the analytical steps leading up to the resulting C^* values, another source of potentially large errors was discovered. The transmissivity of clean Whatman tape was found to vary along the tape by seemingly insignificant

values; however, this "insignificant" variation in I_o may introduce large percentage errors into the resultant C^* values because of the logarithmic transformation of I_o and I. For a given sampler and sampling time this random error in C^* increases with decreasing optical density. Therefore, one would expect the correlations using C^* to be better in winter (when the optical densities are relatively high) than in summer, and likewise better during the morning and evening periods than at noon. Such a trend is apparent between seasons, but not between times of day, especially during the heating season. Markee,[14] in relating C^* to vertical temperature difference, also found that the correlations resulting from summertime data were in general significantly lower than those of winter.

The exponent of C^* in the derivation of Equation 10 had a value of unity; in Table II, the statistical estimate of this exponent for the St. Louis data ranges over nearly one order of magnitude, all of the values being less than unity. This indicates that the optical density of the soiled tape and of the atmosphere are unequal. Unfortunately, since the physical and chemical nature of the particulates were unknown, one cannot explain the varying relationships of the optical densities of the two mediums. Within the range of the C^* data encountered, the optical density of the soiled tape is less than the (computed) optical density of the atmosphere from which the sample was drawn.

This study encompassed a number of "incidental" time-consuming tests that were considered necessary, although they were not directly in line with the original objectives. The digressions have resulted in a modification of the timing device on the Model S AISI sampler, and an evaluation of the potential errors in C^* (discussions of both will be presented elsewhere at a later date).

Summary

It has been shown that visibility is significantly related to C^* and relative humidity, using short-period observations. The relationships tested, however, would permit predictions of the soiling properties of the atmosphere only at relatively low levels of confidence, i.e., the predictions of C^* from visibility might be considerably in error. Important questions that are at present unanswered are: (1) Would time- or class-averages of the data reduce the random scatter of points, resulting in a significantly better relationship? (2) In the light of the potential error in C^*, can we say at this time that a better form of relationship can be found? Another important point to ponder is whether or not the visibility, with the appropriate humidity correction, is in itself a better indicator of air quality than the widely used C^* parameter.

Acknowledgments

I would like to express my appreciation to all of those who cooperated in the many tedious tasks associated with this study; in particular to Mr. Francis Pooler, Jr., for his many helpful suggestions throughout the study; to Mr. Charles E. Zimmer, for his comments and assistance on the statistical procedures; and to Mr. Donald Licking for his supervision of the card punching and computor analyses of the data. Acknowledgment is also due Mr. J. H. Carter, Chief, Division of Smoke Regulation, City of Saint Louis, Missouri, for providing tabulations of the C^* data collated with the U. S. Weather Bureau data from Saint Louis.

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A New Method for Massive Dust Exposures by Inhalation

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A chamber has been designed which delivers a massive inhalation dose to anesthetized animals in a short period of time. The chamber consists of a vertically mounted cylinder with exposure ports arranged so that only the animals' heads are in the dust cloud. Studies have been undertaken exposing Albino rats to strontium and rare earth oxides in the chamber. Data indicate that reproducible chamber concentrations are achieved, and that uniform pulmonary deposition of test material proportional to exposure time is accomplished.

IN chronic toxicity studies, involving the respiratory tract and lung, it is necessary to provide a continuous challenge by the test agent over a long period of time. This is best accomplished by extended exposures to the inhalation of the agent at low-level concentrations. When particulates of an inorganic compound or of a mineral substance are to be evaluated, the type of study described is very time consuming and expensive. Consequently, intratracheal injection techniques are sometimes used for study of relatively insoluble forms of the test agent.

Intratracheal techniques have several shortcomings which make their use limited to the qualitative aspects of a screening method. The principal drawback to intratracheal injection methods is the considerable high local concentration of the test agent in certain segments of the lung. That localization is quite unrealistic in terms of human exposure by inhalation which results in the uniform deposition of the aerosol in all functioning lobes of the lung.

Another important shortcoming of intratracheal injections is the uncertainty regarding the percentage of material retained versus the amount originally introduced into the lungs. Past studies of pulmonary retention, involving several insoluble compounds administered by intratracheal injection, have shown that 20% to 80% of the administered dose is expelled within twenty-four hours. The expulsion of this relatively large percentage usually occurs within a short time, principally due to a coughing action. Subsequently, there is usually very little additional loss of material, as evidenced by a study in which 120 albino rats showed an average retention of approximately 40% of the injected dose, as long as six months after the initial injection.

In order to eliminate the pitfalls attending the intratracheal technique, a chamber has been designed whereby animals may be exposed to the inhalation of massive concentrations of the test aerosol. This chamber was designed with several criteria in mind, which were as follows:

(1) The inhalation exposure must be reproducible in terms of aerosol concentration and of duration.
(2) The chamber must be satisfactory for use in producing exposure to low-level energy concentrations of radioactive materials.
(3) Materials used in the chamber must be capable of being recovered if their availability is limited or if their cost is appreciable.

An exposure chamber which meets the first two of our objectives has been described by Leach, *et al.*[1] That chamber was designed to house a large number of small animals for studying the effect of prolonged exposure to low level concentrations of dust. In brief, the aerosol is produced with the use of a Wright Dust Feed Mechanism which introduces dust into the throat of a venturi mounted in the supply air duct, and the dust ladened air is transported into a plenum chamber. The chamber, operating at slight negative pressure, blends an aliquot of the dusty air from the plenum with its own air supply. The effluent air is filtered prior to discharge into an exhaust stack.

Baurmash, *et al.*[2] have described a dust inhala-

This investigation supported in part by the United States Atomic Energy Commission.

tion chamber designed to produce continuous or intermittent exposures, of animals housed within the chamber, to atmospheric concentrations of the test agent ranging from .08 mg/ft³ to 0.35 mg/ft³. This chamber is equipped with a mechanical device which provides a continuous and uniform amount of dust to be introduced into the supply air. As the aerosol enters the chamber it is deflected radially, by a conical baffle, toward the periphery of the large chamber where the animal cages are situated. The cages are rotated within the chamber to insure uniform exposure of all animals. The exhaust air is passed through filters to remove particulates and discharged outdoors. The two chamber designs described are well suited for low level dust exposures of long duration but do not meet our requirements for the reclamation of the test agent and for producing single or repetitive massive aerosol exposures of known pulmonary dosage.

In view of the criteria previously established, a chamber was designed as a closed system with exposure ports arranged so that only the nose of the experimental animal is exposed, thus simplifying the problem of decontamination. The exposure chamber, Figure 1, consists essentially of three sections constructed of thick plastic cylinders with supporting fittings of aluminum and brass.

Referring to Figure 2, the dry aerosol is mixed

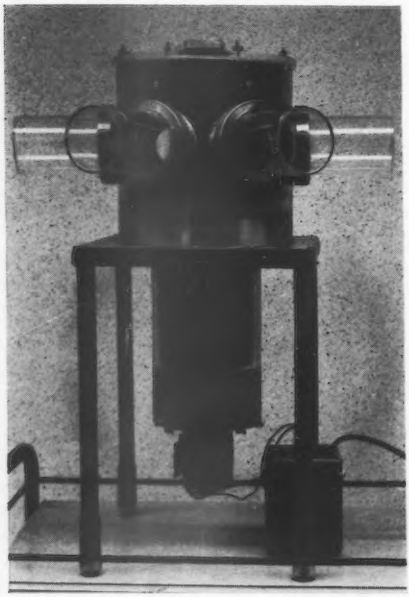

FIGURE 1. Dust inhalation chamber.

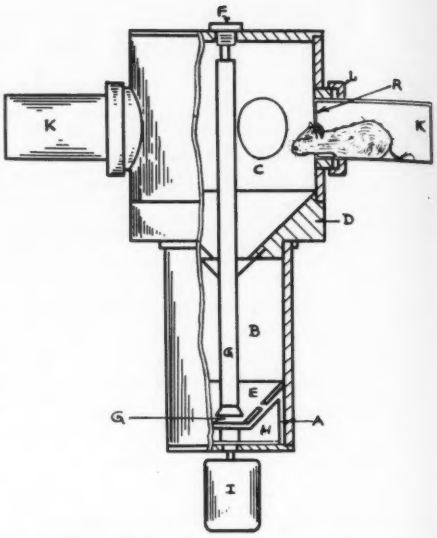

FIGURE 2. Dust generator and animal inhalation chamber:

A. Dust generator section, plastic.
B. Coarse dust removal section, plastic.
C. Animal inhalation section, plastic.
D. Joining block with coned center, aluminum.
E. Cone piece with 6 holes, ⅛" diameter, plastic.
F. Positioning screw for return-air column and dust entry, brass.
G. Return-air column and dust entry to generator, plastic.
H. Radial-bladed fan wheel.
I. Variable-speed motor, maximum 6000 rpm.
R. Rubber diaphragm, for sealing animal in position.
K. Animal holders, plastic tube.
L. Threaded-ring holder for tube.

with air by a radialbladed fan, H, in generator section A. The speed of rotation of the fan is controlled by a variable voltage transformer on the motor, I, and speeds up to 6000 revolutions per minute may be attained. The aerosol is expelled, through six small holes in cone E, into the coarse dust separating section B. Here, the agglomerates fall out of the air and return to the fan. The volume of air passing through the inhalation section C is controlled by the width of the opening between the cone-shaped outlet of column G and the intake of the fan. Column G is raised or lowered by the positioning screw F. Sections C and B are joined together by an aluminum piece D. The top of C and the bottom of B are sealed to their respective sections by machine screws.

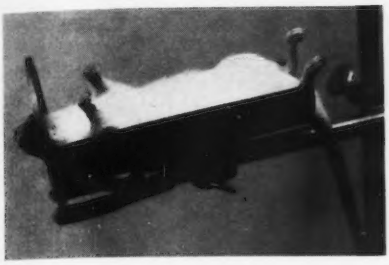

FIGURE 3. Albino rat in exposure position ready for insertion into chamber port.

Section C contains six round ports located symmetrically around its periphery. The animal holder K is a plastic tube, one end of which is sealed while the other end is fitted to a round soft rubber diaphragm at R. The front end of the holder also contains a plastic collar and a threaded ring of metal L. The holder K slips inside of a port and can be sealed in place by tightening the ring L.

For exposure, the nose of the animal is projected through a properly sized hole in the rubber diaphragm or through a molded rubber face mask as seen in Figure 3. The animal is then placed in the plastic holder K, and attached to a port in the exposure plenum.

The extent to which the body of an experimental animal may become contaminated is extremely limited and this feature of the chamber makes it useful for exposing animals to aerosols of radioactive materials at low radiation levels.

Studies have been made to define the operating characteristics of the chamber with respect to the reproducibility of dust concentration achieved, the particle size distribution of the dust cloud and the pulmonary retention of the test agent. The compounds chosen for this study are related to biological investigations of these materials which are in progress.

Chamber Air Concentration

Lanthanum oxide was introduced into the chamber at point F in Figure 2. The dust charge was fed in one-gram increments at five-minute intervals after starting the fan. Air samples were collected on flash-fired fiber glass filters located in one of the exposure ports at animal breathing zone level. Air was drawn through the filter for thirty minutes at a sampling rate of 115 ml/min during six charging cycles. The remaining exposure ports were utilized in four series of tests which were conducted while exposing albino rats to the lanthanum oxide. The chamber concentrations achieved are listed in Table I, and it is noted that two exposures in the first group are much greater than all remaining values. The two high values were found to be due to electrostatic charges produced on the chamber wall and on the dust particles within the chamber. When the chamber was grounded a reasonably uniform dust concentration was achieved. The measurement of dust concentrations was extended to include observations on the behavior of yttrium oxide and cobaltic oxide aerosols in two other chambers. The average chamber dust concentrations from a series of runs made on different days are presented in Figure 4. The lower exposure concentrations produced with yttrium and cobalt oxides are probably due to differences in fan characteristics of the three chambers used, and not to differences in the density or particle size distribution of the test agents.

TABLE I

Chamber Aerosol Concentrations
Lanthanum Oxide
(milligrams/cubic foot)

Test #	Exposure Series #1	Exposure Series #2	Exposure Series #3	Exposure Series #4
1	63.2	70.5	36.9	67.3
2	143.8	60.7	41.0	61.6
3	61.5	50.8	73.0	51.8
4	108.5	—	—	—
Mean	94.3	60.7	50.4	60.2

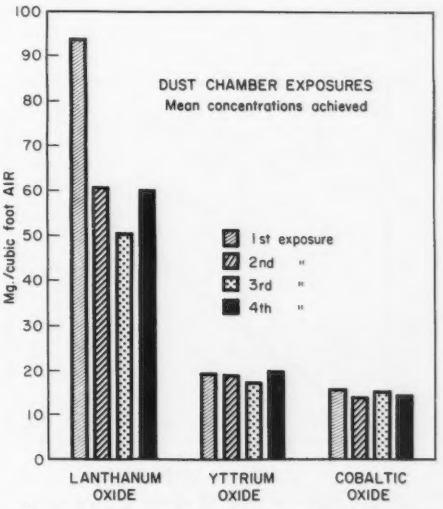

FIGURE 4. Comparison of average dust concentrations produced using three different test agents.

Particle Size Distribution

Studies of the relation between particle size and pulmonary retention have been reported by Brown, *et al.*[3], Van Wijh, *et al.*[4], and others.[5, 6, 7] These workers have shown clearly that dust particles having a diameter greater than five microns are largely removed from the air stream in the nostrils and upper respiratory regions, and further, that only the finest particles reach the alveolar bed. It has been demonstrated[6, 7, 8, 9, 10] that the efficiency of pulmonary retention of dusts is quite high in the particle size range of one to three microns.

It was not possible to examine submicroscopic particles with equipment available in our laboratory, but numerous particle size analyses on samples of the dust cloud generated within the chamber showed that median particle diameters well below three microns are achieved. Comparison of the bulk feed material with the air samples revealed that the dust cloud was consistently enriched in fine particles. The dust cloud, therefore, was almost entirely within the physiologically important range of particle sizes. This enrichment showed the effectiveness of the chamber dust separating section in retaining the larger particles and returning them to the fan section.

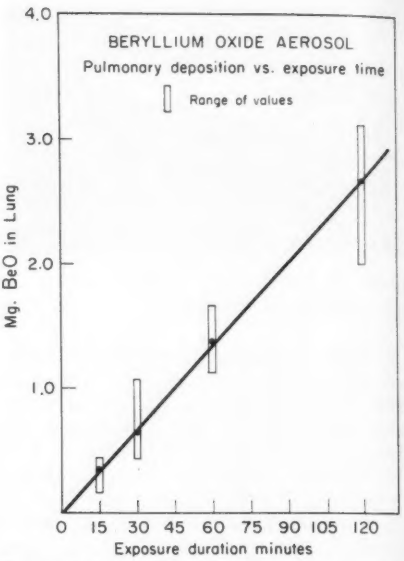

FIGURE 6. Comparison of exposure time and pulmonary retention of inhaled beryllium oxide aerosol.

Pulmonary Retention

Since the aerosol, of any given compound, generated in our chamber is found to be quite uniform and reproducible both with respect to particle size distribution and concentration, the animal exposures are varied by reglating the length of exposure. If any biological (pathological, physiological and biochemical) changes are invoked in the lungs of the experimental animal, it is desirable to define the aerosol challenge to which the animal was subjected so that the changes may be correlated with the dose received by the lung. Animals exposed to strontium oxide and beryllium oxide aerosols for varying lengths of time were sacrificed, and their lungs analyzed to determine the effectiveness of varying exposure duration.

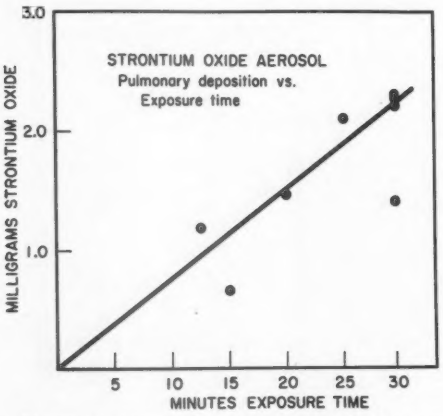

FIGURE 5. Comparison of strontium oxide pulmonary deposition with duration of exposure.

Data describing the exposure period and the quantity of the inhaled aerosol recovered from the lungs of the test animals are presented for strontium oxide, Figure 5, on the basis of nine samples. These data show a reasonable correlation between exposure duration and the amount of dust retained. The data shown in Figure 6, utilizing the beryllium oxide exposure, cover a greater range of exposure time than in the case of strontium oxide exposure, and involved a larger number of animals. The points through which the curve is drawn in Figure 6 represents the mean value of BeO recovered from each group of animals. Variables which may be presumed to have a distinct bearing on the amount of dust found in any given lung include the size of the animal and the depth of anesthesia induced. In this experiment, both male and female rats rang-

ing in weight from 120 to 400 grams were used. The depth of anesthesia induced in the animal was kept fairly constant by using a dose of sodium thiamylal based on body weight.

Summary

A chamber has been designed which permits the brief inhalation exposure of experimental animals to a massive concentration of a dust being studied for its biological activity. Within the framework of this specific study, data are presented which show that reproducible chamber concentrations of dust are achieved, and that uniform pulmonary deposition of the test agents proportional to exposure time is accomplished.

The chamber facilitates the reclaiming of scarce or expensive test dusts by utilizing a closed system from which the dust can be washed into a reclaiming tank or otherwise removed.

Exposures to low energy radioactive dusts can be accomplished with a minimum contamination of the animal body since only the nose of the animal is projected into the dust cloud. The chambers are small and accordingly two may be used simultaneously in a standard laboratory exhaust hood. Operating the chambers in a hood permits the safe handling of toxic dusts by trained personnel.

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Cardiovascular Agents

THE NATIONAL ACADEMY OF SCIENCES—National Research Council has announced the publication of the first volume of a three-volume *Index-Handbook of Cardiovascular Agents*. Pertinent information has been drawn from 13,427 scientific papers, monographs, and reviews. Each entry distills to one or more lines of essential content, indexed according to chemical and biomedical terms. This volume is comprised of more than 100,000 descriptive entries in alphabetical order. Special features include the standardization of all chemical names, translation of all titles of papers with notation of original language, and extensive cross referencing of biological and medical subject headings.

Over 400 scientific journals, published from 1951 to 1955 were examined in preparing the current volume, which has been labeled Volume 2 of the series. Volumes 1 and 3, to appear within the next two years, will cover 1931–1950 and 1955–1960 respectively. Volume 2 is in two parts at $15 for the set. Orders may be directed to Printing and Publishing Office, National Academy of Sciences—National Research Council, 2101 Constitution Avenue, N.W., Washington 25, D.C.

Environmental Monitoring at Georgia Nuclear Laboratories—AFP 67

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The environmental monitoring program initiated at AFP-67 consists of two parts: on-site sampling and off-site sampling. The on-site program provides data on the changes in concentration in the environs and is used for protecting plant personnel from any hazard which might occur. The off-site program provides a continuous record of the fluctuation in background levels and of the effectiveness of the plant radiation controls. The off-site and on-site environmental monitoring programs, consisting of the sampling of soil, vegetation, water, air, animal and marine life, and dose measurements using film, foils, chemical dosimeters and ionization chamber dosimeters, are discussed.

Introduction

THE Georgia Nuclear Laboratory, AFP-67, operated by the Lockheed Nuclear Products Branch for the United States Air Force, was planed to pursue a unique objective in the production of nuclear aircraft design data by dynamically testing and evaluating aircraft components and major subsystems under conditions of realistic flux and environment.

The Georgia Nuclear Laboratory[1] is located on an 11,000 acre site approximately 50 miles north of Atlanta, Georgia, in a sparsely populated area in the foothills of the Blue Ridge mountains. Two reactors, the Radiation Effects Reactor (RER) and the Critical Experiment Reactor (CER), designed by the Atomic Power Equipment Department of the General Electric Company from a conceptual design by the Nuclear Branch of the Lockheed Aircraft Corporation, are located on the site. In addition, the Radiation Effects Laboratory (REL), consisting of large controlled environment hot cells and testing facilities, and the Nuclear Support Laboratory (NSL), are included in the Georgia Nuclear Laboratory complex. The CER is used to determine core configurations for the RER where the components and subsystems are irradiated. Irradiated materials are transferred from the RER to the hot cells in the REL by means of a railroad hot materials transfer system (HMTS). CEF and REF refer to the Critical Experiment Facility and the Radiation Effects Facility. (See Figure 1.)

The RER is designed to operate at 10 megawatts (MW) with a high fast neutron leakage current of 2.8×10^{11} neutrons/cm^2/sec.[2] It is a heterogeneous, pressurized light water moderated and cooled reactor. The RER has a core of 26 modified MTR-type fuel elements, four fuel cadmium poison control rods, and a cadmium-silver regulating rod. The core, consisting on approximately 5.4 Kg of uranium highly enriched in U-235, is contained in an aluminum inner tank, a stainless steel pressure vessel, and an aluminum shield tank with variable water thicknesses. The reactor is supported and raised to an operating position above the 38-foot deep storage pool by means of a hydraulic lift. Operation of the reactor is performed from a control room located in an underground concrete building.

Purpose of Environmental Monitoring

Nuclear safety at a reactor site or installation which uses isotopes or radiation generating machines may include some, or all, of the following functions, depending on the size, type, and operation of the facility:

(1) radiation monitoring,
(2) personnel monitoring,
(3) environmental monitoring,
(4) waste disposal and decontamination,
(5) hazard evaluation,
(6) meteorology.

The operation of a reactor site creates many radiation control and safety problems—one of which is the release of solid, liquid, and/or gaseous radioactive materials and their effects on

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the surrounding environment. The release of radioactive materials to the environs may occur in one of the following ways:

(1) the emission of small undetected amounts of radioactive materials over a long period of time.
(2) controlled discharge of radioactive waste to the environs.
(3) the direct activation of materials around the reactor building with subsequent erosion and release to the environs.
(4) release of radioactive materials from a nuclear accident.

The radioactive materials released to the environs may present an external radiation hazard or eventually enter the human body by inhalation, ingestion, or transfer through the food chain. In order to ensure that the operation of a reactor presents no problem to personnel employed at the Georgia Nuclear Laboratories (GNL), or personnel living off site, it is necessary to measure exposure rates and radioactivity concentrations in the environs of the site and area surrounding the plant.

The evaluation of the effects of plant operation is complicated by the contribution to exposure rates and radioactivity density of cosmic radiation, other natural radiation, and fallout of bomb debris. The dose in soft tissue from cosmic radiation, for example, may vary from 2×10^{-2} rad per year to 5 rad per year, depending on altitude and magnetic latitude.[3] The effects of fallout on external and internal exposure levels will vary with size and number of tests and time elapsed since the last test.

FIGURE 1. Plot plan of Georgia Nuclear Laboratory. The dotted circle is the location of the fence 3600 feet from the Radiation Effects Reactor. The broken line about the entire site represents the perimeter fence.

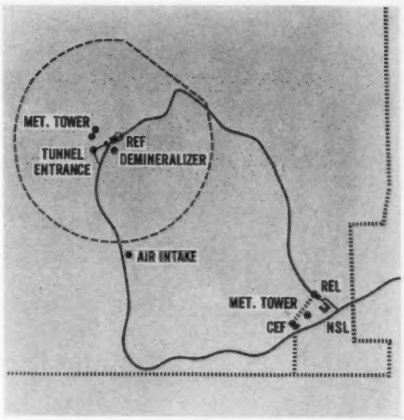

FIGURE 2. Locations of air sampling stations for measurements of activity in air outside the buildings.

On-site Program

Work associated with environmental monitoring was started early in 1956 when the United States Geological Survey initiated a geological and hydrological study of the present GNL site for radioactive waste disposal and hazards analyses. The environmental monitoring program was initiated in 1957 to provide basic background data on radioactivity density found in ground and surface water, soil, and vegetation. Established procedures were used for sample collection, preparation, analyses, and evaluation.[4]

The program has been expanded and adjusted to meet operating requirements and, at present, it includes the collection of air, soil, water, vegetation, mud, and wild life samples and the measurement of total dose.

Eight air sample locations (Figure 2) were established to detect any increase in air activity as a result of reactor or laboratory operations and to supplement air sampling in various buildings. Four of the samplers are located in the immediate reactor area: one at the demineralizer building (200 feet from the reactor), one at the entrance to the underground pedestrian tunnel (750 feet), and two at the RER meteorological tower (500 feet). The samplers at the tower measure concentrations at two different heights, 150 feet and 300 feet. Air samplers are also located at the entrance of the RER fresh air supply (4,000 feet from the reactor), at the

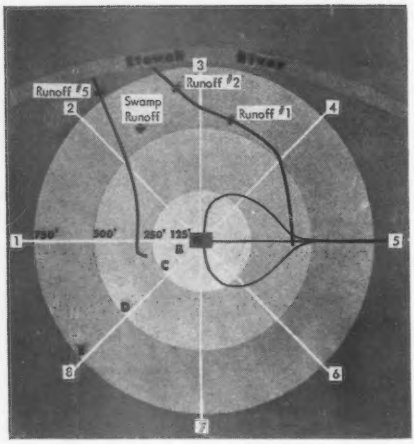

FIGURE 3. Locations of soil and water runoff sampling stations.

CEF, on the roof of the REL, and at the NSL meteorological tower.

Air samples are collected by the week on a 2- × 4-inch HV-70 filter paper, using a Motoair air sampler modified with a special head and running time meter. The samplers are housed in portable shelters to protect them from the weather.

Forty-eight soil sample locations were established around the reactor on concentric rings at the perimeter of the building, 125, 250, 500, and 750 feet from the center of the reactor (Figure 3). A small sample of soil is collected monthly from eight compass points on each ring to determine distribution, quantity, and buildup of activity resulting from soil activation. In addition, 15 other soil sample locations were established, covering the entire site including the two liquid waste seepage pits. These are utilized for background determinations and for detecting any spread of contamination.

Ground and surface waters are collected and compared to concentrations found in rainfall. Eighteen grab water samples are collected weekly from a stream and two rivers located within the boundaries of the Plant (Figure 4). These sample sites were established at locations where activity might concentrate and where wet weather streams enter from the RER or seepage pit areas. The grab samples are supplemented by six paddle wheel samplers which collect continuous samples from the stream and rivers above the reactor site and at two locations below the reactor. These samplers may also be calibrated to supply a record of average river flow during the sampling period.

The work of the United States Geological Survey resulted in the construction of some 26 test wells and 175 auger holes. These test wells and auger holes are sampled routinely to establish and to maintain background level of ground water and to determine direction and rate of flow of liquid wastes which have been placed in the seepage pits. Approximately one liter of water is collected routinely from each location; however, for some special analyses, as much as five gallons may be required.

Vegetation samples are collected at quarter-mile intervals along some 32 miles of roads on

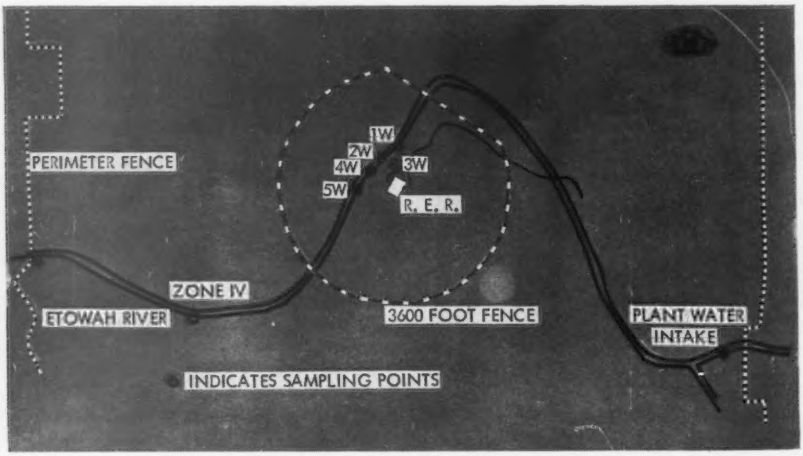

FIGURE 4. River water sampling sites.

site. The roads were chosen to cover comprehensively the area around the RER (Figure 5). Small samples (>10 grams) are collected monthly to determine effects of fallout and any uptake from possible surface and ground water contamination.

In 1958, twenty trees were chosen close to seepage pits and other potential sources of contamination to use for annual vegetation sampling. A sample will be collected from the same branch each year and thoroughly washed so that the detected activity will be related to uptake and not to fallout.

Mud samples are collected from most of the 18 grab water sample locations on a monthly basis. These samples are collected about five feet from the bank of the river or from mud bars that build up at the mouth of wet weather streams. This program provides data on the deposition and build up of radioactive material along the stream and river bottoms. In addition, at continuous water sampler locations, mud samples are vacuumed from the river bottom at definite intervals across the river profile. Radiochemical procedures require the same amount of mud as soil for the determination of gross beta-gamma activity.

Fish are collected monthly from three traps located in the principal streams. These traps are located so that the migration of possible contaminated fish may be detected. Rabbits and migratory fowl are periodically trapped or killed. Samples of flesh, bone, and gastrointestinal tract are processed for gross activity.

A number of methods are used in determining the total dose depending on the dose rate involved, climatic conditions, and the purpose of the measurement. Twenty-six pair of non-self-reading dosimeters located on the 3600-foot reactor exclusion fence and the perimeter fence are processed weekly to determine any significant change in radiation levels. These dosimeters are charged to read 20 mr full scale. Approximately 48 gamma film dosimeters are collected from the fence positions and other points of interest. Neutron film is not used because of fogging from high gamma dose rates in the radiation zone and image fading in areas of lesser radiation.

Lockheed and Emory University are jointly supporting an AEC study program on the "Ecological Effects of Radiation at the Lockheed Reactor Site." In connection with this program, the environmental monitoring group has been supplying the total dose measurement for ecological test sites. At the present time, measurements are made at some 25 locations using film and chemical dosimeters for the gamma dose and cobalt foils for integrated neutron dose. These measurements will be supplemented by additional methods to determine neutron energy distribution, energy sensitivity, and rate effects of the various dosimeters.

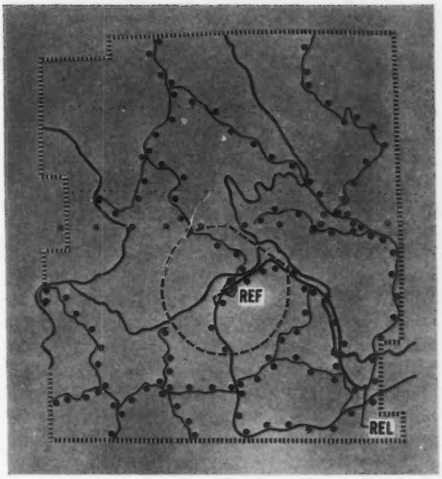

FIGURE. 5. Vegetation sampling sites.

A program has been initiated to determine dose rates at AFP-67 during operation. Surveys are made during reactor operation inside the 3600-foot fence in radiation fields up to 500 mrem per hour. When the program is finished, isodose maps will be made for the entire radiation field around the reactor with various shielding configurations and power levels.

Off-site Program

Several soil, water, and vegetation sample locations were established off site around the perimeter fence at the same time that the on-site program was initiated in 1957. The sampling continued until late 1958 when the program was halted temporarily pending a decision by the Lockheed legal and public relations departments concerning the effects of an expanded program on the public. The present program, which consists of air, soil, mud, water, vegetation, and total dose measurements, was initiated early in 1959. A group of Lockheed public relations and nuclear safety personnel and a representative from the Georgia Public Health Department contacted each person directly affected by the program to explain the type of measurements to be made and the purpose for each measurement.

Air samplers are located at 11 schools in a 50-mile radius of the GNL. These samplers are operated and the air sample filters changed by

the high school science classes. The air filters are returned to the GNL each week for processing. Lockheed has been supplying the science classes with air sample results, scientific demonstrations, and speakers in return for their cooperation.

To cover completely the 50-mile radius area, five additional samplers are located at fire towers and employees' homes. The samplers are operated continually and maintained by Lockheed personnel.

Water samples are colected daily by selected personnel from three cities located on the Etowah River and returned to GNL monthly. In the summer of 1958, Lockheed and the Georgia Public Health Department jointly installed continuous water samplers on Shoal Creek, Amicalola River, and Etowah River above the site and at three locations on the Etowah River below the site. These samples are collected weekly by Public Health personnel and divided between the two organizations for comparison of analytical procedures. Twenty-seven grab water sample locations were established within a 10-mile radius early in 1959 to supplement the continuous samplers and to provide a record of concentrations found in city water and wells at private residences near the site. These grab samples are collected weekly by environmental monitoring personnel.

In addition to limitations on radioactive concentrations in air and water, the total dose to uncontrolled personnel is the remaining item specifically governed by Federal Regulations. To determine the levels involved, dose measurement sites were established at 30 residences within a 10-mile radius. Non-selfreading dosimeters are read weekly to allow early detection of doses in excess of established limits. Film dosimeters are also maintained at the same locations and processed monthly for a permanent legal record.

Soil, mud, and vegetation samples are collected from most of these 30 residences to use as a baseline in evaluating on-site samples. This baseline would also be valuable in determining magnitude and direction of contamination should a nuclear accident occur.

Analysis and Evaluation

All environmental samples are processed for gross beta-gamma and alpha activity by the Lockheed Nuclear Measurements Department. Standard procedures or modifications are used for these analyses.[5] Special samples and samples with unusually high activity are analyzed on a gamma spectrometer to determine quantity and type of contributing isotopes. The results of these samples in disintegrations per minute per unit mass or volume are then recorded by sample type and location. The results are analyzed to determine changes in concentration; fractional MPC's are calculated from the isotopic results to determine total effect from Georgia Nuclear Laboratory operations. Sample activity is plotted by months to determine any significant trends and to detect any area of buildup.

Summary and Conclusions

An extensive environmental monitoring program was established at AFP-67 to determine background concentrations. Approximately 1000 meausrements are made monthly to maintain a comprehensive picture of radiation levels from "naturally" occurring isotopes and plant operation.

To date no significant contamination or radiation levels have been detected except in the area immediately surrounding the reactor. The maximum permissible concentrations established by Federal Regulations have not been exceeded in the environs inhabited by controlled or uncontrolled personnel.[6]

Acknowledgments

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Radioactive Waste Disposal at the Georgia Nuclear Laboratory

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A system of mixed bed demineralizers is used on the 10 megawatt reactor to reduce radioactivity in liquid waste to low levels. Chemical treatment is also provided in the liquid disposal systems. Solid radioactive wastes are buried. Geological and hydrological parameters control selection of areas for infiltration basins, storage, and burial. Sampling and monitoring of both wastes and the environment show that permissible limits of activity have not been exceeded.

Introduction

THE Georgia Nuclear Laboratories (GNL) is located 45 miles north of Atlanta on an 11,000 acre tract. The laboratory is operated by Lockheed Aircraft Corporation for the United States Air Force to provide design data for components of nuclear powered aircraft. These data are obtained by the subjection of various aircraft components and sub-systems to realistic radiation fluxes and utilization of facilities for pre-, current, and post-irradiation testing. Determinations are made on the extent of radiation damage and neutron activation.

The primary irradiation facility is the Radiation Effects Reactor (RER). This is a 10 megawatt water-cooled reactor unique in that in its operating position it is essentially air shielded. When not operating the RER is lowered by a hydraulic lift into a water-filled storage pool. All reactor operations and control of testing environment and result data are accomplished in an adjoining underground operations building. Test articles are brought into irradiation position on specially constructed railroad flat cars.[1] After irradiation the test articles are moved, by railroad, to hot cells in the Radiation Effects Laboratory (REL) for dismantling and physical testing.

A low power (80 watt) swimming pool Critical Experiment Reactor (CER) is used to perform reactor physics studies on cores and reflector geometries intended for use in the RER. The internal components of these reactors are similar. Time savings and increased safety are therefore obtained by using this experimental facility rather than the high-flux RER.

The various components of the GNL generate quantities of radioactive wastes. Low- and intermediate-level liquid wastes are created by reactor operations, and low activity liquid wastes result from laboratory work. Solid radioactive wastes of a large variety are generated by all of the facilities. In addition, reactor operations create gaseous wastes, primarily Argon-41. However, since gaseous wastes are disposed of only by atmospheric dispersion at the GNL, the discussion will be limited to a description of the disposal of liquid and solid radioactive wastes.

Liquid Radioactive Waste Disposal

Radiation Effects Facility

The Radiation Effects Facility (REF) consists primarily of the previously mentioned 10 MW Radiation Effects Reactor (RER), which is heterogeneous, pressurized, and light water-cooled and moderated. It utilizes 26 2-S aluminum clad highly enriched uranium fuel elements (alloyed with aluminum), one silver-cadmium regulating rod canned in aluminum, and four cadmium poison control rods. Structural materials in the reactor consist of 304-L stainless steel and 52-S and 2-S aluminum to minimize corrosion.[2]

The primary cooling system is of the forced convection type. Pressure is maintained at 150 psig by a nitrogen-water pressurizer. Equilibrium temperature is 120°F or less, maintained by two in series heat exchangers with counter flow secondary water. A minimum primary coolant flow of 3200 gallons per minute (gpm) is maintained by two centrifugal pumps.

While high purity (<1 ppm solids) is maintained in the primary coolant by an 18-ft³ capacity mixed bed by-pass demineralizer, some corrosion products become activated by neutron bombardment. In addition, small quantities of

Presented at the Twenty-first Annual Meeting of the American Industrial Hygiene Association, Rochester, New York, April, 1960.

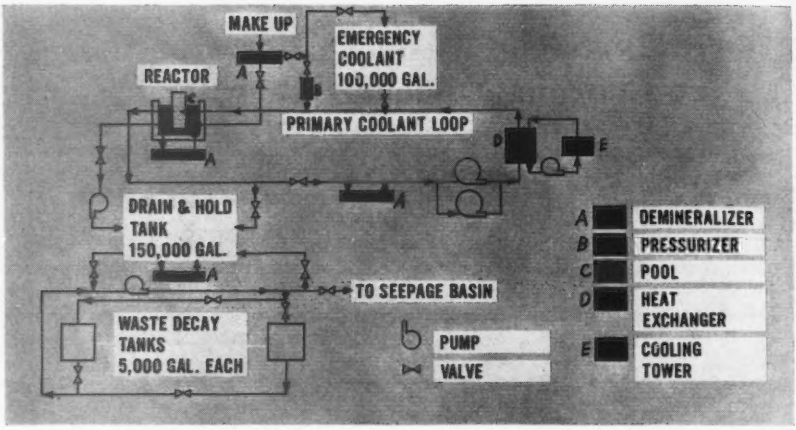

FIGURE 1. Schematic diagram of the Radiation Effects Facility pool and waste disposal system.

fission products may escape the fuel elements and enter the coolant. Should a fuel element rupture or develop a pinhole leak, larger quantities of fission products would be released.

Activation of corrosion products or impurities in the 57,000 gallon reactor pool is another source of radioactivity. Pool purity is maintained at a high standard by an 18-ft³ capacity, mixed-bed pool clean-up demineralizer.

Because of the use of corrosion-resistant stainless steel and aluminum structural material and the demineralizers, liquid radioactive wastes generated by the RER are not high-level under normal operating conditions. Only in event of a fuel element rupture would excessively high levels of radioactivity occur. About one million gallons per year of low- and intermediate-level waste are created by the RER.

The primary coolant from the RER is valved for gravity flow into a 150,000 gallon drain and hold tank. (The primary coolant and radioactive waste disposal system is shown in Figure 1.) The reactor pool water may be pumped into this tank, and it acts as the collecting point for all of the contaminated drains in the reactor and operations buildings. Except for these contaminated drains, waste water is of high purity. Once in the drain and hold tank, the waste may be continuously recirculated through an 18-ft³ capacity waste clean-up demineralizer until acceptable water chemistry and radioactivity levels are reached. This demineralizer is designed to provide decontamination factors of 10^3 to 10^4.[2] The intermediate-level wastes generated by the RER are thereby reduced to low levels.

In addition to the drain and hold tank, two 5000-gallon waste decay tanks are provided for storage and decay of higher level wastes which may be generated by the RER in the event of a fuel element rupture or other accident. These tanks are stainless steel and wastes may be subjected to flocculation or precipitation treatment, pH adjustment, or other chemical processes.

When the waste is in acceptable form, both chemically and radioactivity-wise, it is pumped over 1200 feet into a 100,000-gallon capacity infiltration basin. This is a pit excavated in soil to a depth of about 10 feet, with bottom dimensions of 10 x 30 feet and top dimensions of 40 x 60 feet. The sides are covered with coarse rip-rap and the top by a galvanized 1 x 1 inch mesh wire.

The low-level wastes seep from the pit into the soil below, entering the ground water and eventually being released to surface streams. Activity levels per unit volume are reduced by various factors during the period the isotopes are trapped below ground. These factors serve to effectively bring the content of radioactivity in the wastes below the maximum permissible concentrations (MPCs) of radioisotopes in water as stated in the *Federal Register* and *National Bureau of Standards Handbook 69*.[3]

Critical Experiment Facility

The Critical Experiment Facility (CEF) houses a low power (80 watt), open pool Critical Experiment Reactor (CER) which is used to test the criticality of core configurations which may be used in the RER. The internal components of the CER and the RER are almost identical; the same number and type of fuel elements, control rods, and regulating rod are used. The CER is

housed in a 26,000 gallon pool of water deionized by a 17.1-ft³ capacity mixed bed demineralizer. The pool water provides the coolant and moderator for the reactor and is continuously recirculated through the demineralizer at a rate of about 28 gpm. Structural material in the CER is predominately 304 stainless steel.

Because of the low power in conjunction with water purity and corrosion-resistance of structural materials, activity levels in the CER pool are kept very low.

The pool water of the CER is the only source of liquid waste at the facility with the exception of small volumes produced when the resins of the pool makeup demineralizer are regenerated. As stated previously, the waste is high-purity with very low radioactive content. The pool may be recirculated through the demineralizer until desired chemical and activity standards are met.[2]

A 2,000 gallon glass-lined steel, chemical reaction tank is provided to receive waste water pumped from the CER pool. Any chemical treatment required for later direct release to the environment will be performed in this tank. When the waste is in all respects satisfactory, it is released by gravity flow from the tank to a drainage ditch.

Radiation Effects and Nuclear Support Laboratories

The Radiation Effects Laboratory (REL) and Nuclear Support Laboratory (NSL) are located in the same area and have a combined system for disposal of radioactive liquid wastes as shown in Figure 2. These laboratories create low-level wastes by the testing of equipment contaminated or activated by the RER, decontamination of equipment, and the use of radioisotopes for research, calibration, and radiochemistry. These wastes differ from the high-purity water wastes from the reactors in that they may contain oils, greases, detergents, chemicals, particulate matter, and wide ranges of pH which to various degrees complicate their disposal. However, radioactivity levels are generally low.

Drains for contaminated liquid wastes from both the REL and NSL flow into one of two 20,000-gallon stainless steel waste holdup tanks. A mercury manometer reading pneumatic system is provided for determining the liquid level in the tanks. When one becomes 75 per cent full, it is shut off and the waste is diverted into the other tank. Integrated samplers activated by air pressure are provided for each tank.

The liquid wastes from the laboratories are of varied composition. Chemical additive ports are provided for each tank and the wastes may thereby be adjusted for pH, subjected to flocculation, precipitation, or other treatment. Each department contributing to the laboratory disposal system is responsible for limiting the input of deleterious materials such as oils, greases, particulate matter, detergents, etc., so that the capacity of the system for chemical treatment is not exceeded. When sample results indicate the waste is in satisfactory condition, it is pumped to a nearby infiltration basin similar in design to the pit into which wastes from the REF are disposed.

Solid Radioactive Wastes

Solid radioactive wastes of varied types and activity levels are generated at all of the various

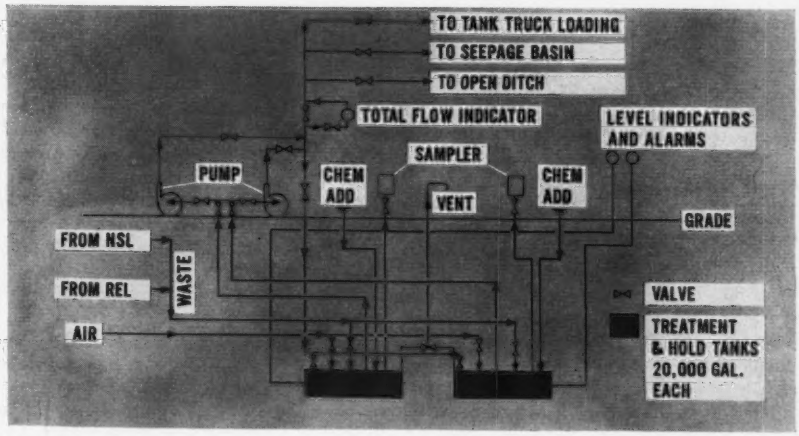

FIGURE 2. Schematic diagram of the radioactive liquid wastes disposal system of the Radiation Effects and Nuclear Support Laboratories.

facilities of the GNL. High-level, small volume wastes are packaged in special, shielded containers at the facility producing the wastes and are directly shipped offsite for disposal elsewhere.

Low-level, large-volume wastes are regularly collected from the various departments. They are transported to a fenced area and placed in 55-gallon drums for storage. This material consists of used contaminated protective clothing, activated soil samples, broken gas masks, paper swipes and towels, laboratory glassware, filings, tools, and a conglomeration of many other items. Presently all of this low-level material is stored. Studies are being conducted in connection with the development of an onsite burial ground for these wastes, which will provide for their ultimate disposal.

Geology and Hydrology

Extensive investigations into the geology and hydrology of the site with particular emphasis on the liquid infiltration basin areas and the proposed solid waste burial area have been made. Hydrogeologic parameters control the movement, decontamination, and dilution afforded radioactive wastes by the method of ground disposal.[4]

The area is one of highly crystalline metamorphic rocks which have been folded, faulted, and recrystallized. Relatively deep weathering has provided a mantle of saprolitic clay which acts as the primary aquifer and receives the waste material.

The sharp topographic relief and heterogeneous nature of the aquifer provide a limited effective areal extent, which is beneficial for radioactive waste disposal operations in that wastes cannot migrate long distances underground and out of the controlled area. In the case of the GNL site, they will emerge at surface streams before leaving the fenced area.[2]

Four factors are the main contributors to effective overall decontamination of low-level radioactive liquid and solid wastes when ground disposal is used. They are ion exchange, filtration, dilution, and decay.[1]

The ion exchange capacity of the saprolite effectively removes and holds portions of the radioactive constituents contained in the wastes. Ion exchange capacity determinations have been made on 126 samples of saprolite taken in disposal areas from 0 to 18 feet in depth using the potassium-permanganate method. These have averaged 5.2 milliequivalents per 100 grams, and in combination with the tremendous quantities of soil involved, it is expected that this will provide substantial decontamination factors, probably in the order of 10^3 to 10^4. Laboratory studies have been planned using soil columns to test the accuracy of these estimates.

Soil samples taken from disposal areas contain 20 per cent by weight of particles of four microns or smaller diameter. These will provide effective physical filtration of radioactive particles with a diameter of four microns or larger.[1]

Wastes migrating through the soil will eventually enter the ground water table and the radioactivity per unit volume will be reduced by dilution. Field tests indicate these will be by a factor of four or five to one (Bowen, unpublished data, 1959). Upon the eventual release of the wastes to streams, further dilution will be accomplished by these surface waters.

During the time waste materials are retained in and shielded by the earth, radioactive decay will operate to reduce activity levels. This will be especially effective for shorter-lived activation products. Liquids migrating through the soil move very slowly; field tests indicate a maximum rate of about one foot per day. In order for the migrating wastes to reach eventual release in surface streams, several hundred feet must be crossed requiring a minimum time of a few years.

Sampling and Analyses

Liquid wastes are individually batch sampled before release to the environment or infiltration basins. If adjustment is indicated, this is done and the wastes resampled. This process continues as long as is necessary—until wastes are in acceptable form for release. In most cases, however, only a single sample of each batch is required.

Samples are processed by boiling down 500 cc and transferring the residue into an aluminum planchet. Dilute nitric acid is used to wash the residue if appreciable particulate matter is contained. The planchet is counted by internal proportional flow counters modified with an aluminized mylar film window for gross beta-gamma activity. If the indicated activity is lower than the established MPCs, no further radiochemical analyses are necessary. If MPCs are exceeded, however, further determinations on the isotopic content are made by using spectral analysis or separated by co-precipitation for gamma activity and ion exchange techniques for beta emitters. Standard analytical chemistry methods are used to determine stable isotopes (Askew, unpublished data, 1959).

The pH is determined on each sample and the amount of total contained solids is run on samples when the need is indicated.

Maximum Permissible Concentrations

Based on minimum decontamination factors provided by infiltration basin disposal, an MPC

of 1×10^{-5} microcuries/milliliter (μc/cc) of gross beta-gamma activity for wastes containing no alpha emitters or Strontium-90 has been established for pit disposal. Wastes released directly to the environment must be less than MPC's stated in the *Federal Register* and *Bureau of Standards Handbook 69* (1×10^{-7} μc/cc for gross beta-gamma).

It is expected that continued use of the infiltration basins will provide data which will permit a substantial increase in the MPC's for wastes disposed of in this manner.

Environmental Monitoring

An inclusive system of environmental monitoring is in effect to determine the amount and types of radioactivity present in the soil, water, air, vegetation, and wildlife both on- and off-site. This program includes total dose measurements and the collection and analyses of many types of samples. Special attention is paid to the Etowah River, which bisects the site and receives the surface and ground water drainage from the waste diposal areas.[5, 6]

The environmental monitoring program serves as a final check on the efficiency of ground disposal of radioactive wastes, as any deficiencies or so called "leaks" will be detected in the samples.

Summary

Radioactive wastes generated at the GNL are disposed of in a safe and economical manner by utilizing several principles. First the amount of radioactivity produced in reactor coolants is kept to a minimum by the use of high purity water produced by makeup demineralizers. Secondly, the radioactive waste produced in the coolant is removed by and concentrated with demineralizers. And thirdly, the factors of decontamination provided by ground disposal of solids and low-level liquids have been proved very effective.

As a result of these precautions, radioactive waste disposal at GNL has not exceeded, and is not expected to exceed, MPC's in the site effluents.

Acknowledgment

The assistance of persons supplying data for incorporation in this report is greatly appreciated, especially that received from W. T. Price, K. R. Holtzinger, J. A. Mohrbacher, R. B. Askew, W. T. Scarborough, and F. P. Harmon of Lockheed Aircraft Corporation, and J. T. Callahan and J. W. Stewart of the Atlanta Office, Ground Water Branch, U. S. Geological Survey.

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Certification of Health Physicists

THE AMERICAN BOARD OF HEALTH PHYSICS has certified more than 150 applicants as accredited radiation protection experts. The board was established last year by the Health Physics Society to provide uniform standards for radiation protection specialists. State regulatory codes specify functions and responsibilities of radiation safety supervisors but until the new board began to function there was no qualifying provisions or supervisory licensing group in industry. Certifying examinations have been held in Boston, Atlanta, Chicago, and San Francisco. Additional applicants will be certified during the next few months. To be admitted to the examination, candidates must have a bachelor degree in science or engineering and a minimum of five years of experience in a responsible position in health physics.

A Study of Occupational Radiation Exposure in New York State

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A statistical study of occupational radiation exposure in New York State industry, based on personnel monitoring records, survey data and results of medical examinations, was made by the Labor Department. Exposures were classified by source, occupation and industry. The results indicated that over 90% of the exposures were below the NCRP recommended dose limit of 100 mrem/week, and that the contribution of occupational exposure to the general population dose was less than 0.3%. The highest external exposures noted were among workers in radium processing, luminous dial painting, industrial radiography and nuclear fuel element fabrication. Sampling results indicated that air-borne concentrations of radioactive contaminants in all but a few installations were below 10% of the MAAC.

INDUSTRIAL Code Rule 38, entitled *Radiation Protection*, has been in effect in New York State since December 1955. The responsibility for the administration and enforcement of this code has been assigned to the Division of Industrial Hygiene of the Department of Labor.

Among the provisions of the Code are requirements for:

(1) Registering with the Industrial Commissioner the type and size or rating of all sources in an installation, which is defined as a location where one or more sources of radiation are used, operated, or stored;

(2) Surveying each installation to determine dose rates and duration of exposure for each employee;

(3) Monitoring of personnel wherever surveys indicate that the exposure may exceed 25% of the maximum permissible dose as defined in the code for both internal and external sources;

(4) Controlling airborne radioactive material by means of local exhaust ventilation, isolation, respiratory equipment or other effective means to maintain the average concentration within specified limits;

(5) Requiring the owner of each installation to maintain records of surveys, dosimetry readings, medical examinations and other pertinent data.

The code defines over-exposure as a dose in excess of 3 rems of external radiation, or an equivalent internal exposure over a 13 week period.

Since there is a requirement for maintaining records of radiation survey data as well as clinical and dosimetric information on individual employees, a study was designed to determine:

(1) The degree of radiation exposure by occupation, source, and industry.

(2) The relationship between dosimetric and survey measurements;

(3) The contribution of occupational exposure to total population dose, and

(4) Whether industry can readily comply with the lower dose limits proposed in a revision of the State radiation protection code.

Method

Questionnaires were designed to gather clinical and dosimetric data on file at the installations. They contained space for identification of the firm, the individual employee and for recording the type, duration and intensity of occupation exposure. An attempt was made to obtain information on past medical radiation exposures as well. Monitoring and air sampling data were recorded in appropriate subdivisions as either internal or external exposures. There was also provision for recording clinical data such as blood counts and radioactive bio-assay of urine and expired radon.

The questionnaires were mailed to 245 firms in which personnel monitoring, air sampling or urinary bio-assay had been performed as a control measure. A separate form was used for

Presented at the Twenty-first Annual Meeting of the American Industrial Hygiene Association, Rochester, New York, April 27, 1960.

recording the pertinent data for each exposed individual. The firms selected for the study were chosen on the basis of information available through the requirements of the code. Installations having the greatest potential hazard were included.

The requested air sampling data were available in the records of 27 plants where surveys determined that the air-borne concentration might, at any time, exceed 25% of the maximum allowable concentration.

Ion chamber dosimeters were worn in several industries as a check on the accuracy of the film badge readings or to give an immediate indication of excessive exposure. Exposed personnel in most plants included in the study used film badge monitors, worn on lapels or attached to belts. In some installations exposure to the hands was determined by attaching a badge to the wrist or finger.

Improper care, storage and processing of monitoring devices may result in erroneous readings. Moreover, the low and high readings reported by many commercial film badge services appear as "less than 50 mrem" in the one case, or as "greater than 5 rem" in the other. Such reporting is too obscure for the purpose of statistical analysis. Therefore, appropriate allowances were made which consisted of analyzing the data in terms of the median rather than the average exposure and by using the interquartile range rather than the standard deviation.

Results

Seventy-two per cent of the 245 questionnaires were returned. The returns furnished data on 4829 employees or just over 95% of the workers in New York State exposed to radiation in December 1958, at the beginning of the study. Personnel monitoring data on nearly 186,000 man-weeks of exposure, representing 2408 employees, were recorded and tabulated. The results are shown in Table I, which includes a breakdown into whole body and hand exposures. Personnel monitoring data for the remaining 2421 employees were either incomplete or insufficient for analysis.

The totals in Table I represent 50% of the radiation workers in the State and include those occupations where exposure in excess of 100 mrem/week occur. It would appear that 95% of the occupational exposures to radiation are below 50 mrem/wk. This conclusion is supported by the fact that monitoring is required for all occupations in which survey data indicated that exposure might exceed 25% of the maximum permissible dose. In 36 industries for

TABLE I

Summary of Study of Occupational Exposure to Radiation in New York State Industry, 1950–59

Number of occupations	105
Number of industries	36
Number of individuals	2408
Number of types of sources	27

	Man weeks monitored	% Weekly exposures > 50 mrem
Total	185,918	9.5
Whole-body	174,109	7.9
X-rays & gamma	168,937	8.1
Neutrons	5,172	0.0
Hands	11,809	32.1

which the information was recorded, only 7.9% of the whole body weekly exposures were equal to or greater than 50 mrem.

No neutron exposures over 50 mrem occurred. One-third of the hand exposures were in excess of this figure, but the permissible exposure level for extremities is 1500 mrem.

Figure 1 presents typical occupations in which 100 or more man-weeks of whole-body exposure were monitored, with no recorded exposures over 50 mrem. The figure indicates that the instrument manufacturing industry handles a variety of radiation sources safely, and that the use of A.E.C. licensed isotopes and gauging devices does not pose a major hazard. Similarly, the exposure to operators of industrial x-ray machines in fixed installations is minimal.

Figure 2 shows the sources of hand exposure to employees in a similar group of occupations wherein all the monitoring data recorded were below 50 mrem/week.

Figure 3 gives the sources and industries in which weekly exposure data exceeded 50 mrem in at least 50% of the determination. The actual range was 50–87%.

Figure 4 shows the industries and occupations in which less than 50% of the weekly whole body exposure determinations exceeded 50 mrem. In the aircraft industry and in industrial testing laboratories, where radiographers and technicians use unshielded mobile x-ray units and gamma-emitting isotopes of curie strength, measurements over 50 mrem/week occurred over 25% of the time. Exposures to medical x-ray, diffraction units and to particle accelerators were less than 50 mrem in over 95% of the dosimetric determinations. These data represented the experience of 16 medical and dental x-ray technicians, 3 supervisors in a research and develop-

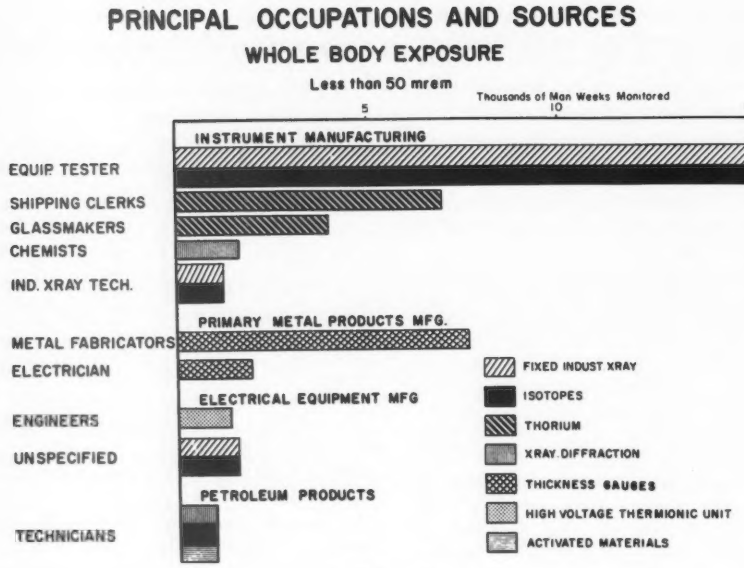

FIGURE 1.

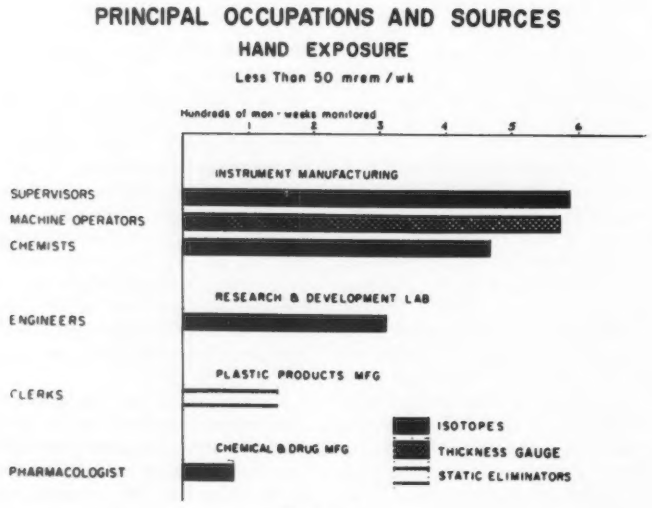

FIGURE 2.

ment laboratory, and 9 physicists working with particle accelerators which generate both x-rays and neutrons.

Figure 5 demonstrates the interquartile ranges of whole body exposure for a number of occupations recording weekly dosimetric readings in excess of 50 mrem. For medical x-ray technicians working in industrial medical departments, practically all exposures were below 50 mrem per week. However, chemists in the radium processing industry sustained exposures over 50 mrem in 88% of the total weeks monitored with

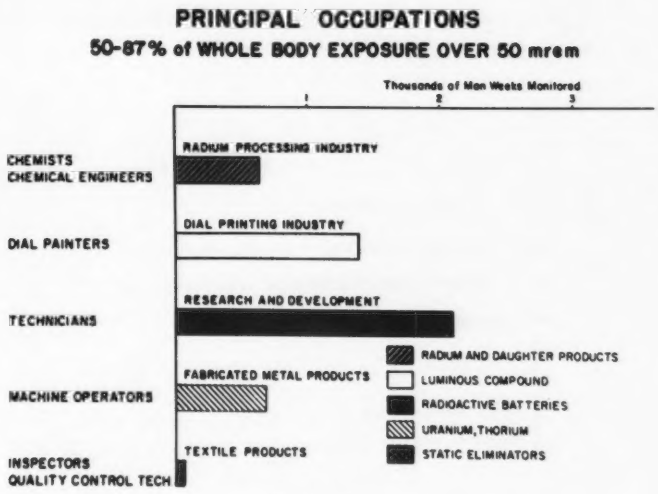

FIGURE 3.

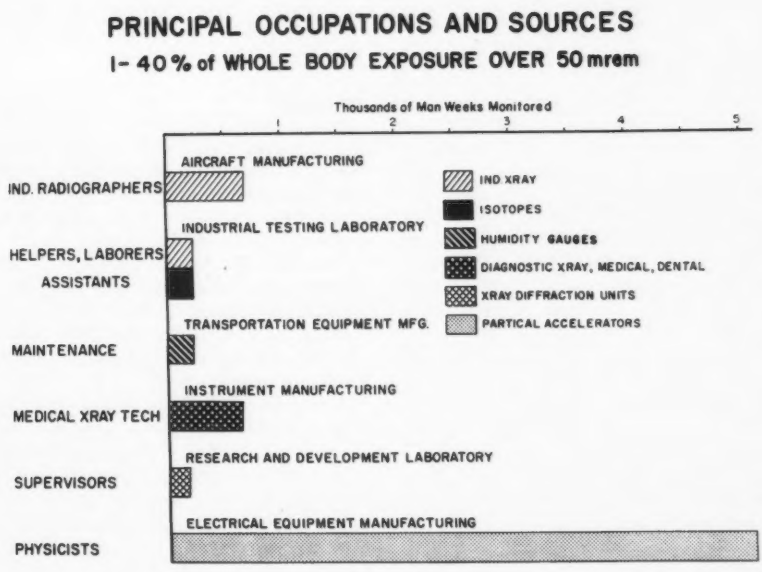

FIGURE 4.

the interquartile range extending from 250 to 475 mrem. A wide range of readings was also obtained for research and development technicians, who work with radioactive batteries; dial painters and textile inspectors.

Table II contains hand exposure data in which there were weekly readings for beta or gamma exposure over 50 mrem. In radium processing, radioactive metal fabrication and research and development activity in battery manufacturing determinations over this level occurred over 50% of the time. In the printing industry, where pressmen are exposed to radiation from static eliminators, approximately 20% of the dosimetric

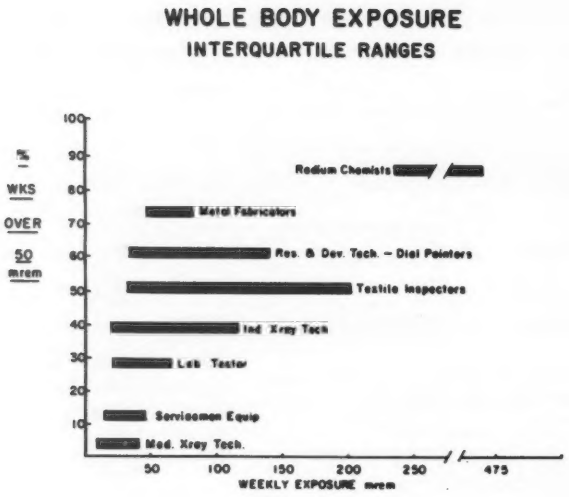

FIGURE 5.

TABLE II

Hand Exposures

Occupation	Total man-weeks monitored	Type of radiation	Inter-quartile range	Per cent of weeks over 50 mrem
Maintenance mechanic, radium processing	77	Beta	43–168	70.1
		Gamma	172–320	100.1
Silk screen printer, dial painting	288	Beta	37–174	54.5
		Gamma	44–141	61.6
Machinist, fabricated metal products mfg.	116	Beta	42–145	70.5
		Gamma	13– 39	4.5
Technician, research and development lab.	1000	Beta	37–147	66.0
		Brems.	29–161	81.6
Pressman, printing and publishing	496	Beta	15– 45	18.1
		Gamma	13– 38	0.2
Electrician, electrical machinery mfg.	102	Beta	14– 43	11.8
		Brems.	13– 38	0.0
Chemist, research and development lab.	683	Beta	14– 41	2.4
		Gamma	13– 39	2.6

determinations exceeded 50 mrem/week. However, there were no hand exposures in excess of 1500 mrem/week.

Air-sampling was routinely performed in 27 plants where the use of unsealed radioactive material created a potential internal hazard. Only in the radium processing industry, dial painting plants and in the nuclear fuel fabricating facilities, did the average air-borne concentrations of radioactive contaminants exceed 10% of the Maximum Average Allowable Concentration (MAAC). Radioactive battery manufacturers and isotope laboratories maintain air-borne contamination in work rooms below 10% of the MAAC.

Complete tabulations of the environmental and clinical data are in the process of preparation.

Discussion

The influence of certain variable factors which emerged during the survey made it difficult to draw unqualified conclusions. For example, the error in estimating x-ray or gamma radiation exposure from film badge readings may have been as much as 25%. It was considerably greater for estimating exposure to beta, neutron and soft x-radiation. Improper use of dosimeters and leakage of radioactive air-borne contaminants into the ion-chamber type may also have been serious sources of error.

The influence of work-load, occupancy and usage factors should be considered along with the dose-rate in determining a hazard. Personnel monitoring is recognized as of prime importance in the control of exposure. An example of the usage consideration is the fact that the workload of industrial medical x-ray units rarely exceeds one milliampere minute/week.

It is evident that in all but a few of the industries using radiation in New York State, the range of exposures does not exceed 100 mrem/week and that the recommended life-time exposure limit is not being exceeded.

The per capita estimation of the general population dose from background, medical and miscellaneous exposure is 0.35 rem/year. According to our data, the occupational exposure to internal and external radiation hazards, con-

tributed about 0.3% to the general population dose.

Conclusions

The following conclusions were based on an analysis of monitoring data of almost 2500 employees in 105 occupational classifications in 36 categories:

(1) The occupational exposures to radiation are below 50 mrem/week for at least 90% of the radiation workers.

(2) The data showed that there was close agreement between dosimetric and survey measurements.

(3) The contribution of occupational radiation exposure to the general population dose is a small fraction of the amount for medical and other environmental sources.

(4) Industry can readily comply with the lower dose limits recommended by the National Committee on Radiation Protection. In the few exceptions, improved environmental control may be necessary.

Industrial Hygiene Foundation

THE TWENTY-SIXTH ANNUAL MEETING of the Industrial Hygiene Foundation will be held at Mellon Institute, Pittsburgh, Pennsylvania, on October 25 and 26, 1961. The annual meetings of the Foundation have become a firmly established custom and part of industrial hygiene. The position of the Foundation in the over-all field of industrial hygiene and the nature of these meetings combine to fill a unique place in the exchange of information and philosophy of preventing occupational disease. For further information write to Dr. H. H. Schrenk, Managing Director, Industrial Hygiene Foundation, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

Applications of X-Ray Analysis

THE TENTH ANNUAL CONFERENCE on Applications of X-Ray Analysis will be held August 7–9 ,1961 at the Park Lane Hotel, Denver, Colorado. New and improved accomodations including a new conference room will provide comfortable, attractive and effective facilities for the conference.

The Conference will include sessions on Diffraction, Fluorescence, Absorption and Microscopy, and Instrumentation. Titles and abstracts of papers to be considered for the program were due by April 15, 1961. Unfortunately the receipt of the announcement and the publication schedule of this journal were "out of phase" such that a prior notice was not possible for us. Inquiries concerning the Conference should be directed to W. M. Mueller, Metallurgy Division, Denver Research Institute, University of Colorado, Denver 10, Colorado.

Radiation Field from a Rectangular Source

THE NATIONAL BUREAU OF STANDARDS with the support of the Office of Civil Defense Mobilization, the Navy Bureau of Yards and Docks, and the Defense Atomic Support Agency, has developed a series-expansion method for calculating the radiation received by a detector from a rectangular source. The method utilizes information on the angular distribution in the form of coefficients of a Legendre expansion, and determines the detector response as a sum of products of these coefficients and other coefficients characteristic of a particular source rectangle. The resulting sum is accurate provided that either source angular distribution or source rectangle can be described by only a small number of coefficients. Alternative sums are utilized for cases in which the sum described is not sufficiently accurate. These alternative sums represent the angular distribution of the source as a secant power series rather than a Legendre expansion. Details of these methods have been published by J. H. Hubbell, R. L. Bach, and J. C. Lamkin in the Journal of Research of the National Bureau of Standards *64C*, No. 2, pp. 121–138 (1960).

Guarding Against Major Radiation Accidents in a Large City

DANIEL E. LYNCH

New York City Office of Radiation Control, 386 Fourth Avenue, New York 16, New York

The New York City plan for handling radiation accidents relies in the main on control at the accident scene by the Police Department, hazard evaluation by the Health Department and Atomic Energy Commission radiation specialists, a communication plan using telephone and Civil Defense two-way radio, and advance information on storage locations or shipments of hazardous quantities of radioactive material. Possibilities of accidents to the water supply and certain other accidents not covered in the plan are discussed.

THE New York City Health Code requires radioactive materials, x-ray equipment and other sources of ionizing radiation to be registered with the Department of Health, but the Code exempts certain quantities of radionuclides from registration. The exempt quantities for unsealed sources range from 0.1 microcuries of strontium-90 and yttrium-90 to 1000 microcuries of natural uranium and thorium.

We, in the Office of Radiation Control of the Department of Health, have advised the Fire Department that one million times one of these exempt quantities may be a hazard to firemen and require special care when fighting fires. Such large amounts, according to the registration records, are stored in 49 places in the city and we have given the Fire Department a list of the locations. To be sure that our records in this respect are complete, we consulted the list of Atomic Energy Commission licensees and communicated with those possessing large amounts of radionuclides.

The factor of one million is based on very rough estimates of the quantity of radioactive dust which a fireman might inhale during a short time in an average size room. Allowance was also made for the fact that a fire is an emergency. Fire-fighting necessarily entails some risk and the standards for normal exposure of the public do not apply. The basic idea behind the factor of one million is that one of the exempt quantities listed in the Health Code is likely to give a fireman less than one millionth of the 25 rem allowance specified by the National Committee on Radiation Protection and Measurement for emergency one-time exposure. The rough nature of the trial calculations is compensated by the fact that they actually yielded factors of ten million or more. The application of a single factor to all of the exempt quantities is based on the belief that these quantities are approximately proportional to the tolerances for the various nuclides.

If there should be a radiation accident in New York City it may occur in one of the 49 places on the Fire Department list. However there are very few of these places where a major accident, understanding by this an accident with many injuries, seems possible. Principally they involve sealed cobalt or radium sources used in radiation therapy. There are, in the city, a plant producing reactor fuel elements and a very few other locations where radioactive materials are used and at which a major accident is credible. There are no nuclear reactors in the city and no plants for processing spent fuel elements.

We are especially concerned with possible accidents to trucks or railroad trains carrying radioactive materials. The first precaution in dealing with this problem is a provision of the Health Code requiring notification to the Department of Health before shipping radioactive materials into, through or within New York. It has been necessary to suspend enforcement of this provision until changes requested by the Atomic Energy Commission and other federal agencies could be agreed upon.

Prevention of such accidents depends primarily on the users and shippers of radioactive materials and secondarily on the enforcement by the Atomic Energy Commission and the Interstate Commerce Commission of their regulations and contract provisions. There appears to be little that the city can add. However, dealing with an emergency when it occurs is a problem primarily for the city government.

In any radiation accident the Police Depart-

ment and the Office of Radiation Control of the Health Department are concerned. Other city agencies and other parts of the Health Department may or may not be involved depending on the nature and seriousness of the accident. The Atomic Energy Commission can hardly be left out because the chances are that their materials will be involved and because their skills will be needed.

The Police Department expects to be the first of the city agencies to arrive at the scene of an accident. They have instructed the member of the force first on the scene to notify the Police Borough Communications Bureau. The Bureau will then notify the Police Emergency Service Division, the Police Laboratory, the Police Bureau of Planning and Operations, the Office of Radiation Control of the Health Department, the Atomic Energy Commission and the Fire Department.

Meanwhile the policeman first on the scene, with the help, if necessary, of the Emergency Service men when they arrive in their patrol cars, is supposed to set up a 100-foot radius exclusion area.

We, in the Office of Radiation Control, have an emergency vehicle and one of us proceeds to the location of the accident in it. The Police Commander at the scene is instructed by his department to follow the recommendations of the man from the Office of Radiation Control in the evaluation of the radiation hazard and in the matter of changing the size of the exclusion area. The public is excluded from the area until it has been decontaminated and we declare it safe.

If the accident is indoors the 100-foot radius idea is not practical and in that case the rooms believed to involved are evacuated.

The police part of the plan says nothing about what the Atomic Energy Commission will do after they are notified. The New York Office of the Commission has a trained and equipped emergency team. We expect that this team will respond after they are notified unless it is obvious that the accident is of such a minor nature that they will not be needed. The City Health Department has provided the A.E.C. team members with identification cards showing that they are authorized to act for the city in a radiation emergency. There is close liaison between the A.E.C. and the City Office of Radiation Control so that, for practical purposes, their team and ours are one. In particular we recognize their technical qualifications and will be guided by their advice. Incidentally their vehicle and ours carry instruments and we also have tools for handling and removing small radiation sources.

This plan is not very elaborate but we do not think it needs to be, as long as it has certain essential features. One is that it should be clear who is in charge. The police commander at the scene necessarily has to give the orders. Also the first policeman on the scene, even though he may have little or no knowledge of radiation, must be allowed to take certain precautions without waiting for orders. The second requirement is that someone trained in radiation should respond and that after he arrives his technical recommendations should be followed. Since radiation accidents will probably occur as seldom as once every few years it does not pay for every department to have a specialist in radiation solely for emergency work. The city's radiation specialists are in the Office of Radiation Control. The plan seems to meet the requirements.

Certain other aspects of radiation accidents do not call for advance planning. The matter of decontamination should not require haste and it is therefore left to be worked out in individual cases. While treatment of radiation injuries might require haste, the matter of rushing victims to hospitals seems no different than the same problem in the cases of injuries unrelated to radiation, and in which the police have had long experience. The special part of the problem is the matter of calling in physicians qualified to diagnose and treat radiation injury. We know where to find them.

Contamination of drinking water is a possibility calling for different measures. There is a monitoring program for the city water supply. It is based on grab samples but we are considering installing some continuous monitoring device.

The Department of Water Supply, Gas and Electricity controls industrial contamination on the watershed. The problem is essentially the same whether the industrial wastes are radioactive or not. The novel feature introduced by the atomic age is the presence of fallout from atomic weapons tests but so far the quantities have been very small. They are useful as tracers to help us plan what to do in case of heavy fallout, such as would occur in an atomic war.

New York City depends, in the main, on an impounded surface water supply but there are auxiliary wells which can be used in an emergency on a rationing basis.

We do not regard any of this planning as static. With respect to the water supply there is a great deal to be done in the exchange of information among the city agencies concerned. As one step in satisfying this need, an interagency

committee of technical personnel meets regularly to discuss radiological monitoring of the water.

It is hoped, also, that improvements in the accident plan can be made from time to time. For example we should like to develop surer ways of estimating the doses received by exposed persons in an accident since such information will be helpful in their diagnosis and treatment.

It is possible to imagine accidents, not of the kind discussed above, which may conceivably occur but which seem improbable. One is an accident to the nearest nuclear reactor slightly more than 20 miles to the north of the city. All the available evidence indicates that the elaborate safeguards provided for this reactor are adequate and also the distance from the city is reasonably large.

Military aircraft carrying atomic weapons have crashed before and the possibility of such an occurrence within the city limits or on the watershed has to be considered. We have been told that there is no danger of a nuclear explosion in such a case but that an explosion of a high explosive charge might scatter plutonium.

Another special problem is to foresee the consequences of an accident to a nuclear powered ship in the harbor.

Our policy so far toward these low probability special cases is to collect information about them in preparation for amending our plans, if necessary, to deal with them. The information includes facts about the reactor, the nuclear powered ships, the city water supply system and the flow pattern in the harbor.

Summary

Our first step in planning to deal with radiation accidents was to try to anticipate the possible kinds of accidents and where they might occur. The next step was to arrange to notify persons trained in maintaining order and others trained and equipped for radiation control. This required the cooperation of the Atomic Energy Commission as well as of the City Health and Police Departments. Finally it was necessary to plan for the prompt response of the emergency personnel and for the division of functions among them. Water supply contamination and some other special kinds of radiation incidents are not appropriately dealt with in this way and require special measures.

The Monitron

The Monitron, an instrument using the measurement of light-scattering for the determination of concentrations of aerosols and dusts in air, was described on pages 43 and 44 in the February 1961 issue of this Journal. The matter of the manufacturer and supplier of this instrument was incompletely stated. Engineering Specialties, cited as the source, is in fact a supplier of units to the Monitron Company, 1815 Wilaray Terrace, Cincinnati 30, Ohio. The patents and exclusive sales rights to this instrument are held by the Monitron Company. Inquiries concerning the Monitron should be directed to this company at the above address.

A Proportional Liquid Effluent Sampler for Large-Volume Flows

H. H. Abee and J. C. Hart

Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

A proportional sampler for large-volume liquid flows has been designed, installed, and tested at the White Oak Creek Dam. The basic unit consists of a circulating pump and a collecting vessel controlled by an overflow pipe which varies in height in proportion to the head of the stream. The sampling period is normally 10 minutes and can be adjusted for optimum conditions by regulating the timing mechanism. It is adaptable to wide variations in stream head, requires little maintenance, and minimizes clogging resulting from debris, incrustation, and algae formations.

Introduction

AT Oak Ridge National Laboratory large volume, low level liquid wastes are discharged, after some preliminary treatment, to White Oak Creek, a surface stream which flows through the Laboratory area. In the early stages of the Laboratory's growth, a dam was constructed on White Oak Creek creating a lake to provide additional hold up time for decay and settling of radioactive materials adsorbed on suspended silt. Grab samples collected daily at White Oak Dam were used to evaluate the concentration and quantities of radioactivity released to the Clinch River. To evaluate these quantities more accurately, a sampling device which sampled the stream proportional to the stream flow was desirable.

The Problem

Sampling of liquid wastes to evaluate the concentration and total quantity of radioactivity discharged involves two things: (1) the measurement of the rate of flow, and (2) the method of collecting the sample.

A commonly used device for measuring waste flow is the weir. A weir is a dam or other obstruction which is placed in a pipe, channel, or stream and contains a notch, either V-shaped, rectangular or trapezoidal, through which the waste stream flows. Flow through the weir is some function of the head, the head being defined as the height of the water surface above the crest of the weir in the pool upstream from the weir. Formulas for calculating flow and tables giving flow with respect to head for various kinds of weirs are available in the literature.

Sample collection methods may be divided into two general classes, grab sampling and continuous sampling. The most desirable sampler is the continuous proportional sampler which collects a sample truly representative of the effluent released. The latter collects samples the volume of which is proportional to the rate of flow at the time of collection. To achieve this end, variable pumping rates, variable orifices, or shaped collecting vessels may be used.

Proportional sampling of a stream such as White Oak Creek becomes somewhat of a problem because of the numerous variables which exist. The amount of suspended solids and debris in the water may vary appreciably depending upon the amount of rainfall and the degree of runoff. Algae growth in the water during certain seasons of the year present clogging problems which hamper accurate sampling with certain types of samplers. The stream head on the weir may vary from a few inches to as much as several feet; thus, the flow varies from a few cubic feet per second to several hundred cubic feet per second. As is often the case where a small dam is concerned the lake level behind the dam is controlled by the raising and lowering of a sluice gate. Consequently, the position of the gate determines the crest of the weir. In normal operations the position of the gate must be changed from time to time in order to control waste releases, thus creating one more variable which complicates sampling techniques.

No commercially available proportional sampler has been examined which will handle all of the problems discussed. At ORNL the Trebler Sampler is used for certain types of stream sampling. The system shown in Figure 1 utilizes

Presented at Twenty-first Annual Meeting of the American Industrial Hygiene Association, Rochester, New York, April 28, 1960.

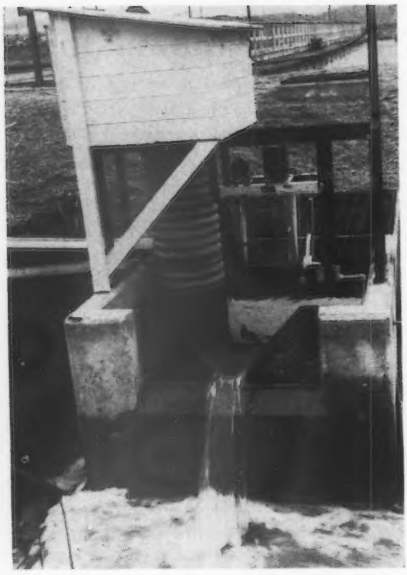

FIGURE 1. Trebler Sampler illustrating the use of 90° V-notch weir.

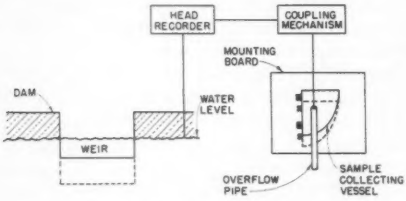

FIGURE 2. Block diagram showing sampling system for use of a shaped collecting vessel in proportional sampling.

a 90° V-notch weir through which radioactive waste water leaves one of the settling basins. Such a sampler is quite useful where the variation in head on the weir covers only a limited range. In the case of White Oak Dam, variation in the head and volume of flow is too great for the Trebler Sampler to be used successfully; consequently, a proportional sampler specifically for use at White Oak Dam was designed.

Design Considerations

Stream flow through the weir at White Oak Dam varies non-linearly with respect to variation in head. Since flow through the weir is a function of the head and since the head variation is normally measured in a linear dimension, compensation for this non-linearity in flow with respect to head must be designed into the sampler. After considering a number of ways for obtaining a sample proportional to the flow, the decision was made to use a shaped collecting vessel approach, illustrated in Figure 2. One can calculate the shape of the sample collecting vessel such that a sample collected will be proportional in volume to the stream flow provided the depth of sample in the vessel is regulated in some linear ratio to the stream head. Control of the depth of sample collected in the vessel is achieved by varying the height of an overflow pipe in the sample collecting vessel.

The shaped collecting vessel method used at White Oak Creek Dam essentially eliminates the common problems associated with methods which utilize variable pumping rates or variable orifices. In these methods of proportional sampling, one loses proportionality due to encrustation resulting from silt and algae deposits or clogging from debris in the water frequently experienced during periods of heavy runoff. With the shaped collecting vessel method, any convenient pumping rate can be used and the pumping rate need not be constant as long as the vessel will be filled in the allotted time. The open collecting vessel can be located some distance from the sampling point, being readily accessible for maintenance and decontamination.

The weir opening at White Oak Creek Dam is defined by the position of the sluice gate, and the crest of the weir will change as the position of the gate is changed. To compensate for changes in gate position which are necessary from time to time, the sampler was designed so that the position of the sample collecting vessel can be changed with respect to the position of the gate. That is, the position of the sample collecting vessel can be changed vertically in direct ratio to the change in gate position while the position of the overflow pipe, which is coupled to the head recorder, remains constant.

Operation

The operation of the sampler may best be understood by reference to Figure 3. Effluent is pumped continuously from the stream through a pressure relief valve and back to the stream. A wire screen is provided at the pump intake to prevent debris from being sucked into the line. At ten minute intervals, a portion of the circulating effluent is bypassed to the sample collecting vessel. This is accomplished by means of a timer unit which effects the opening of a solenoid fill valve in the line running from the pump side of the pressure relief valve to the sample collecting vessel. The effluent rises in the collecting vessel to the level established by the position of the variable overflow pipe. The

volume of effluent in excess of the sample required is drained by the overflow pipe back to the stream. The fill valve remains open for approximately two minutes allowing ample time for the collecting vessel to be filled completely. When the filling cycle is completed, the timing unit closes the solenoid valve in the fill line, then opens the solenoid drain valve at the bottom of the collecting vessel to permit delivery of the sample to the sample storage container.

The position of the overflow pipe in the collecting vessel is governed by the water level or head in the stream. A potentiometer attached to the water level or head recorder will be varied as the water level changes. The change in resistance unbalances the electronic system of a Brown recorder. The recorder re-balances the system, rotating a drum to which the overflow pipe is attached by a wire. The rotation of the drum changes the position of the overflow pipe in direct ratio to the change in head or water level. Thus, with the shaped container and the variable overflow pipe, a sample is collected which is proportional to the rate of flow.

The White Oak Dam unit is shown in Figure 4. It has been in operation for more than a year and only minor difficulties have been encountered. During a period of heavy rainfall, when the silt content of the water was high, the solenoid fill valve selected for the system was inadequate and had to be replaced by a more positive action valve. The packing gland in the effluent pump selected for this system appears to be such as to require maintenance at intervals of about six months. Two pumps have been provided with the sampler to maintain continuous operation during possible breakdown or maintenance periods. During the first year of operation the unit was not operated in such a manner as to give a true proportional sample in that the gate and closing mechanism was being modified. In any case, the system has been proven to be satisfactory and proportional sampling will be achieved following the completion of construction work at the dam and the fabrication of a shaped collecting vessel which will be designed for the dam as modified. (At this point the authors would like to give credit to Frank Markli, a staff engineer formerly associated with the Laboratory, for his contribution in engineering the electronic and mechanical features of the system.)

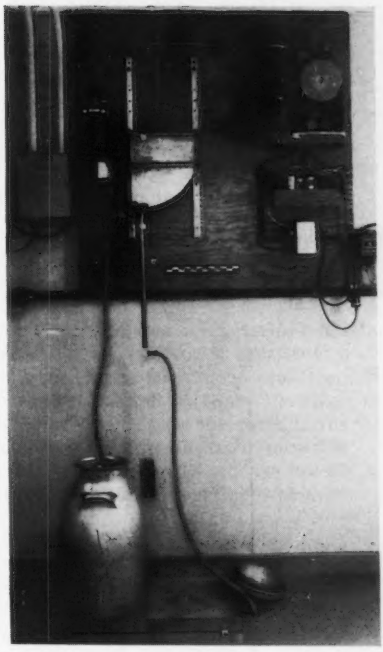

FIGURE 4. Photograph of the White Oak Dam sampling unit.

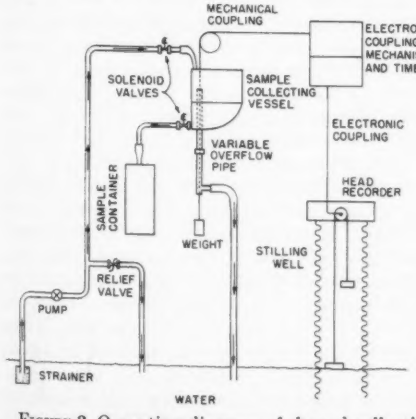

FIGURE 3. Operating diagram of shaped collecting vessel sampling system.

Summary and Conclusion

A proportional sampler has been designed which overcomes certain difficulties associated with sampling surface streams. Such difficulties include algae growth, variation in suspended solid material and debris, and large variations in head. A proportional sampler of this type seems to be particularly suited for use where large changes in head may occur. This approach to proportional sampling appears promising for any application in stream sampling where the head in the stream is measured and flow curves are available to permit calculation of the collecting vessel configuration.

Morale of Workers Exposed to High Levels of Occupational Noise

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An investigation was made of workers laboring under extremely high noise exposures, and a control group of employees subjected to normal factory noise. Through sociometric studies and personal interviews, the administration of a scale especially devised to test job perception as a function of ego-involvement in work, and a review of illness-absence rates, injury rates, and frequency of dispensary visits, it was demonstrated that the Study Group, subjected to the highest noise levels and the most hazardous operational conditions, had a significantly higher level of morale than the Control Group, which labored under conditions which would appear to be far more advantageous. It was concluded that adverse factors such as noise and other disagreeable or even dangerous working conditions, do not determine morale or affect behavior on the job, but rather that high morale results from the worker's perception of his working conditions and his degree of ego-involvement in his job.

Introduction

NOISE control was a prominent subject in industrial health from the boom years of the 1920's to the late depression years preceding World War II. Experimental observations by psychologists began to appear, and pointed to adverse effects of noise on work output and efficiency. The belief was held widely that working in noise-distracting environments caused fatigue, excitability, and nervous tension, that it impaired operational efficiency and caused muscular stiffness—in short, excessive noise resulted in lowered morale and lowered production.

Many of these studies were carried out under carefully controlled conditions, but experimental settings did not compare with our present day work circumstances, or our sound pressure levels, which are as high as 140 decibels, with 180 decibels or more estimated for the future in certain air operations. Further, consideration generally was not given in these studies to certain emotional factors, including the well-recognized individual differences in perception of sensory phenomena, which were determined by a number of personality variables.[1]

In the years following World War II, further studies moved general thinking away from the view which held that noise was totally harmful to health and to production, to that which granted that it might be annoying but it was not productive of a specific behavior response. (The clinical entity of occupational deafness was recognized during this time, but is not germane to this study. It was recognized, also, that noise became definitely deleterious when it masked or interfered with verbal communication.)

Meanwhile, studies of morale, particularly among war-industry workers, flourished during and immediately after the global conflict. Consensus was that this elusive factor, morale, consisted of a strong, cohesive group feeling, with a high degree of identification with the organization, the leader, or the goal pattern. The concept of unity was stressed, and, as Brown[2] put it, "a group of persons is said to have good morale if that group is enthusiastically united in seeking a common goal." Learner[3] commented that, "an individual's estimate of his own prestige, status, and satisfaction is more explanatory of the attitudes comprising morale than are the situational factors dependent on interactions with group members."

After reviewing the literature in these two areas, *i.e.*, occupational noise and morale factors, the authors undertook a study of employees laboring under extremely high noise exposures, using as a control group, workers subjected only to normal factory noise. These two groups of employees were compared through a study of their work records, personal interviews, sociometric studies, job perception tests, and environmental noise levels. The problem was to determine the levels of morale within each group of workers, compare them, and isolate those fac-

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tors involved most critically in determining the level of morale. The hypothesis to be tested was that not from noise or any other environmental distraction, but from the degree of ego-involvement of the individual worker in his job, springs the behavior from which morale is deduced. The "ego-involved" worker is here defined as one who is not merely practicing a certain trade, but who regards himself as a member of that trade, and fully accepts it as defining his own status and role in the economic and social structure, regarding it as an expression of his own skills, abilities, and personal adequacy. Ego attitudes, which thus define the concept of self, are necessarily affectively-charged, and it is hypothesized that the worker's perception of the "good" or "bad" elements of his job will be decided principally by the high or low degree of his involvement in it. This study was directed toward evaluation of those factors which directly affect the development of these attitudes toward work in relation to the self-image.

Design of the Study

The subjects for study were selected from the more than 20,000 civilian employees at an Air Force Base within the Air Materiel Command. The Maintenance Division, with whose personnel this study is concerned, repaired damaged aircraft, and anticipated trouble by completely tearing down and reconditioning engines at specified intervals. Other responsibilities included the modification of new aircraft, the changing of existing armament, and the making of structural and other revisions not accomplished at the factory. Specific areas investigated in this study were group relationships in the plant (including supervisory, administrative, and work relationships) and personality factors. Implementing the project were sociometric studies, personal interviews, and the administering of an E-scale especially devised to assess experimentally the presence or absence of ego-involvement of the workers.

Interviewed and tested were 105 civilian employees. The Study Group consisted of 50 Aircraft Jet Engine Testers, Grades 10 and 15. Their duties and responsibilities included the preparation of jet engines for test, assisting in the installation and removal of the engines from test cells, and the recording of instrument readings while the engines are undergoing test. The work involved walking and standing, close observation of instruments during a test run, frequent lifting of more than 45 pounds of weight, and some desk work while recording instrument readings. The working conditions were described as: "Inside; extremely noisy; possible danger of injury to ear drums; danger if engine explodes." The work was classified as non-repetitive, and it was not done singly, but by groups of men working as teams.

The overall noise level (Sound Pressure Level, SPL) for these engine testers, as measured with the General Radio Company Sound Level Meter, Model 1551A, and Octave Band Analyzer, Model 1550, ranged from 119 decibels to 94 decibels, and the Speech Interference Levels (SIL) ranged from 112 decibels to 86 decibels.

The Control Group, selected from the Parts Overhaul Section, consisted of 55 men from work areas with noise levels considered equivalent to average factory noise. These workers included two groups of personnel: Aircraft Welders, Grades 10 and 15, whose duties principally were performing heliarc and oxygen-acetylene welding, silver soldering, non-destructive testing with "zyglo" fluid, and working with a variety of metals; and Grinding Machine Operators, Grade 11, who worked with portable pneumatic grinders, grinding jet engine compressor rotor blades to specified clearance dimensions and removing burrs from the blade tips after grinding. While both groups of workers were exposed to the minor hazards characteristic of their shop areas and crafts, the overall noise was the "normal shop level" of 76 decibels, with an SIL of 58 decibels.

Group Relations Study

The problem of determining group relationships was approached by two methods: personal interview, and sociometric study. In the personal interviews, workers were encouraged to talk about their social contacts by such questions as: "Tell me about the people you work with. What kind of people are they? How many people do you have to contact every day in order to get your work done? How many do you speak to or have conversation with? If someone in your unit didn't show up for work, would you know it? How long would it take for the news to get around? Do you talk shop?" These questions were used as starting points to elicit the attitudes of the workers toward each other, and to determine the nature and extent of their social contacts. Leads which they mentioned were followed up, and they were asked to elaborate and explain their comments.

The second method of investigation of group relationships was through sociometric study, from which sociograms were constructed. Sociograms, a technique developed by Moreno,[4] yield information pertaining to group structure, leaders and dominant figures, integration and cleavages, clique formations, amount of social

interaction, and hierarchical status of the members. They are constructed on the basis of one criterion question, administered to all subjects, and their validity depends wholly upon the degree to which the question asked refers to real opportunities for association, and to which responses might be based upon the respondent's true feeling, rather than upon limiting factors in the situation. Of four questions used experimentally in the Group Relations Study, only one, "Whom would you prefer to eat lunch or play cards with?", was found to refer to a concrete, continually experienced situation, in which choices were made freely. It was, therefore, on the basis of this question that the sociograms for each group were constructed.

Job Perception Test

This portion of the study was based on work by McGehee,[6] Sherif,[6, 7, 8] and others, and sought to subject to test certain conclusions concerning morale drawn from the previous sociometric studies and relatively unstructured personal interviews. By asking the workers to make a series of judgments about abilities necessary to attain success in their jobs, an attempt was made to test whether workers judged by previous examination to differ as to high or low morale, and as to degree of ego-involvement with their work, would also differ in the standards related to their work. Theoretically, the high-morale, ego-involved worker who looks upon his work as an expression of his own abilities, will feel that qualifications for success in his job are higher than will the worker who is not so involved.

To implement this portion of the project, respondents were assembled in groups and administered a specially devised scale, referred to as the E-scale. This consisted of 25 statements describing hypothetic workers of varying abilities, and the subjects were asked to judge how successful each of these hypothetic workers would be in his own job, rating each on a scale of one to five. The statements in the scale were developed around five popularly conceived, socially desirable "traits": responsibility, initiative, judgment, independence, and intelligence. Five statements were made about each trait, describing five different hypothetic workers who possessed the trait in different degrees. Statements on the mimeographed scale were presented to the subjects in randomized order, according to Tippett's table of random numbers.[9] When administered as a pilot study to 53 nurses at a university medical center, who had been divided into high and low morale groups on the basis of the judgment of the Director of Nursing Services, the scale distinguished between the two groups above the 0.01 level of confidence, with the difference in the direction of greater selectivity in the high morale group.

Absence Rates

Finally, as measures of effectiveness of a personnel group ordinarily are seen in rates of attendance or absenteeism, number of visits to plant dispensaries, rate of turnover, and frequency and severity of injuries, these can be seen also as indicators of high or low morale. Therefore, four factors—absence frequency rate (annual average number of absences per worker), absence disability rate (annual average number of days absent per worker), absence severity rate (average number of days absent per absence), and dispensary visit rates (annual average number of dispensary visits per worker)—were compared for the Study Group and the Control Group.

Results

Group Relations Among the Engine Testers

In Figure 1 is the sociogram of the Study Group, the Engine Testers. Its most striking characteristic is the integration of the entire group. Interconnections reach into every smaller subdivision and to every member, weaving the group into an organized unit. Smaller groupings, or cliques, can be identified by triangular and square arrangements. There are many of them, but the relationships within the cliques are subordinate to the outgoing relationships among them. There are more lines of contact between, than within, the clique arrangements. There are dominant figures, indicated by the larger circles, but the pattern of leadership is not highly defined. The cliques are definite, but loosely knit. There are no cleavages between subgroups. In such a situation, jealousies and subgroup hostilities are not likely to develop. Expansiveness and cohesion take precedence over subgroup rivalry. This is a situation in which the group members react in terms of their experiences with one another and loyalties belong to the group as a whole. The total picture is one of a freely accepting, expansive group, where common interest would be expected to be strong, and antagonism to be at a minimum.

In the personal interviews, liking for their fellow workers was one of the most frequently mentioned reasons given by Engine Test employees for liking their jobs. The sociometric findings and the men's own testimony described a highly cohesive group of workers, conscious of their group membership and of the teamwork character of their jobs. The immediate group

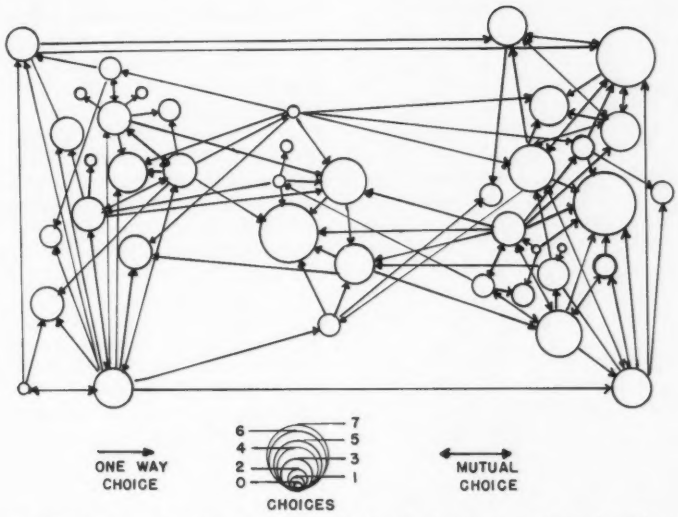

FIGURE 1. Sociogram of engine testers on the basis of selection of lunch and card game companions.

goal, expressed by the workers, is to turn out good engines which will be accepted by the inspector.

From the interview-discussions, a complex of integrated attitudes was evident. Testing an engine was regarded as more than just a mechanical job; it became an accomplishment related to larger social values already incorporated within the individual by his society. "Selling an engine" (*i.e.*, having it accepted by the inspector) meant protecting a pilot's life, building a stronger air force, making a better country. These values apparently were served in Engine Test through the common group effort.

It was noted in the sociogram analysis that patterns of leadership among the engine testers were not highly defined. This was an informal group within a highly organized institutional setting, where formal leadership already was established. The teamwork character of the work itself called for a democratic rather than an authoritarian direction. Assignments were given usually by supervisors to groups of workers, and details of the procedure were worked out among them.

To outward appearances, Engine Test was an undesirable place to work. There was the high noise intensity, the job was dangerous, and there was the constant possibility of explosion or fire from the untested engines. Workers were exposed to the high outside temperatures, since the vented cells could not be heated or air conditioned because of the rush of air set up by the running engines. Further, the work was greasy.

In view of the basic attitudes related by the workers toward their jobs, it was not surprising to find that the unpleasant aspects of their work were minimized. In the interviews, only a few spontaneously mentioned the noise. A larger number mentioned noise when asked what they did not like about their jobs, but with the majority, it was necessary to ask a specific question in order to elicit an expression of feeling about the high noise level. Group norms apparently centered, not upon the unpleasant aspects of the job, but around behavior concerned with the common, cooperative effort —accepting and discharging responsibility, willingness to help out, to teach others, working out group decisions in production problems, and sharing the common interest in test performance. Adherence to these norms resulted in behavior highly consistent with plant production, and from which high morale was inferred.

Group Relations Among the Welders

One important difference between welding and engine testing was that welding was a skill which, at one time in their history, the welders chose voluntarily, and one in which they were employed before coming to the air base, and which they might continue to exercise should they leave. Many had taken special welding courses, and had invested in their own equipment. Thus they were mobile, prepared to practice their

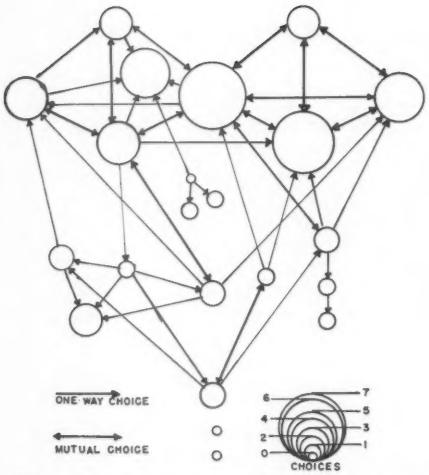

FIGURE 2. Sociogram of welders on the basis of selection of lunch and card game companions.

trade wherever they desired, and opportunity afforded. The stable factor in this career is the weld itself, and it is in this that the welder takes pride. He is creating a weld, not helping to manufacture an object, and he is not involved personally in the function or nature of the product. Unlike the engine testers, the welders had not, therefore, become ego-involved in jet engines, nor were their job satisfactions anchored securely in the functions of the Base. Primarily, they identified themselves as welders, only secondarily were they air base employees. It did not follow from this alone that their work-involvements were less intense, or the gratifications of their work less satisfying. It did mean that there was a basic difference in motivation and that the conditions affecting morale among the welders differed from those in Engine Test. Various welders referred to their work as fascinating, spoke of its lack of monotony, expressed themselves as believing it required a higher degree of skill than the average trade, and described a definite pride in good work.

A second important aspect in which the work of the welders differed from that of the engine testers was in its relatively isolated character. The welder not only was separated physically from others as he performed his job, but the work was an entirely individual matter, accomplished independently of others. There was no cooperative effort to turn out a single product, no ready-made, shared goal which might be reached by common effort. These conditions would be expected to affect motivations and the nature of the group formation.

In Figure 2 is the sociogram showing group structure of the welders. This is a picture which differs radically from that found in Engine Test. Lacking in the welding sub-unit were the common group effort and production goal, and we find, not an integrated group, but a divided structure consisting of an exclusive, tightly-knit clique dominated by a few individuals, and the relatively more isolated, non-clique welders. The definite cleavage between clique and non-clique welders indicates a break in continuity in acceptance of group norms and group goals. These variations would be expected to arouse variations in attitude toward the job and, therefore, in morale among the workers. As indicated by the material in the personal interviews, this proved to be the case.

Because the welders' work itself involved no common production goal, and only limited opportunities for on-the-job association, this clique and non-clique group formation resulted from social contacts away from the Base. These took place as often as twice a month for the majority of the clique welders; and they seldom were attended by non-clique members.

All the clique members said they preferred welding to any other type of work. As was found with the majority of the workers in Engine Test, most of the clique members discussed principally the attractions of their jobs, and showed the same tendency to minimize job hazards. Despite the fact that most of the clique members enjoyed a higher salary and more variety in their work than most of the non-clique welders, none of them mentioned salary as a reason for liking his job. They expressed loyalty toward their supervisor, and their desire to be responsible to him. They wanted directives to come through him, and not directly from the higher levels of authority, and to him they brought all their problems. This identification of the supervisor with the men was in all probability related to the fact that the position was vertically mobile —because of the system of retention points, supervisors often were demoted back into the ranks. In every group interviewed there were found workers who once had been supervisors, and there was only a small differential in salary. The supervisor's authority was limited, and in most cases he could only pass requests for raises and other benefits on to his superiors, all of which served to define his interests more sharply with those of his workers.

Most of the welders represented on the sociogram as non-clique had lower salaries, performed repetitive work, and did not have the opportunity to handle different metals and learn a variety of welding processes. In the personal

interviews, six of the non-clique welders said they wanted to leave welding. While only one of the clique members offered criticism voluntarily, complaint was offered spontaneously by nine of the 12 non-clique welders. These complaints came out early in the interview, and occupied a major part of the discussion. They projected the frustrations and insecurities felt by the workers as a consequence of their peripheral position in the group with which they would identify. They described a sense of isolation, of being dealt with arbitrarily, or of being discriminated against.

Within this kind of psychologic milieu, unfavorable aspects of the job loomed large. They tended to emphasize, not minimize, job hazards and inconveniences. Nearly all of the non-clique group said welding was hard on their eyes. They described the work as strenuous, unhealthful, "nerve-racking," and fatiguing. They complained of fumes, difficulty in getting raises, and uneasiness when work was slack. The chief complaint voiced by the non-clique welders, however, was of partiality, particularly with regard to the system of loan-outs to other departments, a system almost universally disliked by all the workers.

The pronounced feelings of insecurity engendered during periods of slack loads were mentioned by only one of the clique members, but described repeatedly by the non-clique members. It was evident that the uncertainty of this situation made it a threat to job security. In the absence of authoritative information, the workers could only guess what the slack periods presaged. Rumors arose and anxiety increased. In the non-clique group, already insecure in their peripheral group position, these anxieties were common. Lack of definite knowledge about organizational functioning—who was responsible for decisions about sick pay and holidays, the schedule of loan-outs, or the standards required for step raises—was shown in the interviews of clique and non-clique welders alike. In this ambiguous situation, the aggression of the complaining non-clique welders was, in general, directed vaguely toward "them," a term which included the several levels of supervisory personnel—the supervisor, foreman, and general foreman.

The foreman, one or two steps removed from the worker, had the function of coordinating personnel with demands of a production schedule. A frequently expressed desire of the foreman was for help in meeting these problems through supervisory training. Several foremen pointed out that their training was in mechanical areas, and that they felt inadequately prepared in their job of understanding the problems of the men under them.

Apparently, one of the needs of this group, in both welders and supervisory personnel, was for more information, clarification of plant policies and functions, and supervisory training. In the absence of objective information, judgments were formed subjectively, and widely differing preceptions of the work and working conditions were found to be associated with variations in the attitudes of the welders, attitudes which had been shown to be related to the worker's feeling of acceptance and belongingness, and his group status.

Group Relations Among the Grinders

Like the welders, most of the grinders worked alone, completing, independently of others, the operations on the engine parts assigned to them. As it was with the engine testers, their work was assigned to them after they came to the Base, and they learned it on the job. Unlike the work of the other two groups, all the grinding jobs were classified as repetitive.

Lacking here were the conditions related either to group formation or to ego-involvement. The grinders had neither the welders' identification with a chosen, recognized craft, nor the shared effort and production goal of the engine testers. It was not necessary for them to know the identity of the part on which they were working, or its function in the completed engine. For them, the tangible goal of their labor did not extend beyond the immediate grinding of cracks, nicks, and burrs.

In Figure 3 is presented the sociogram of the grinders. Its most striking characteristic, in comparison with the sociograms of the welders and engine testers, is the sparseness of the friendship choices, and the number of isolates and near isolates. In the entire group there are only four reciprocating choices, and only one clique, of three members. The seven choices received by one member of this clique apparently reflect his personal likeableness rather than the exercise of leadership qualities, for he does little to weld the group together. An opposite phenomenon is the worker who received no choice and made eight. A newcomer, not yet well-established enough to receive any choice at all, he was actively seeking the companionship of his new acquaintances. His radiating choices give a spurious appearance of integration to the configuration.

In personal interviews, 17 of the 24 workers in the grinding unit said they hoped for a transfer. Recurring throughout their interviews was the feeling that they could not see what they

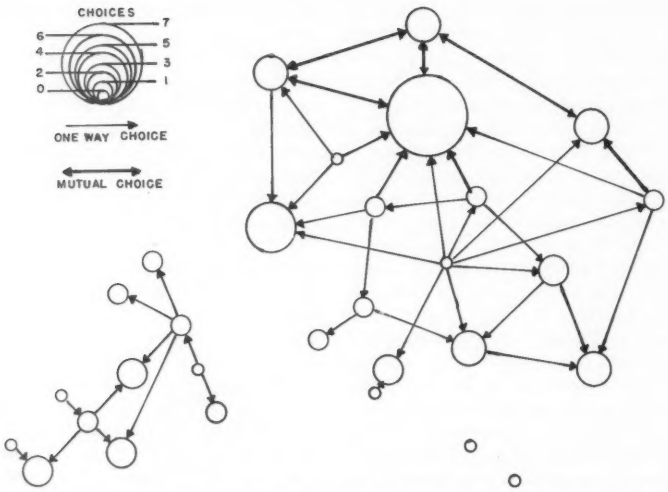

FIGURE 3. Sociogram of grinders on the basis of selection of lunch and card game companions.

were accomplishing, and did not feel the importance of their work—and therefore of themselves—in the overall scheme. They found their jobs consisting of repetitive, continuous processes, unpunctuated by completed units of work which they could regard with satisfaction, and not calling for all their abilities. Where the engine testers wanted "good" engines, and felt their time had been wasted when one had to be returned for adjustment, the grinders showed no such concern over the number of satisfactory nozzle diaphragms which they completed. Further, only about one-fourth of them could give an accurate statement of the function of this part, or its place in the engine. They expressed dissatisfaction with this lack of information, and a desire to know more about their work, but the attitudes which were verbalized expressed a marked lack of ego-involvement in it. There was nothing of importance here to which they might belong. Their disinterest was reflected in the affectively neutral, matter-of-fact discussion of the good and bad points of their work. They spoke with neither the enthusiasm nor the lively resentments found in the other two groups. Criticism was minor and tempered. Several expressed disappointment over not having received raises. Others mentioned dust from the grinding machines, flying steel, "eyestrain," noise, lighting, and standing. Asked what they liked about their work, reaction again was mild. Most of them expressed a liking for their supervisors, but other mention of job attractions was meager. Apparently, they did not perceive the purpose and usefulness of their own work as they compared it with other jobs around them which yielded more tangible results. They did not see where their work and, therefore, they themselves, fitted into the picture. There was a consequent feeling of unimportance, of lack of belongingness, in the total scheme of the Base.

This basic mood was demonstrated probably most revealingly in the attitude of the grinders toward the interview itself. In Engine Test, there was little evidence that the interviews held much personal import to the workers. They accepted the explanation that this was part of a study of plant conditions in which they were asked to cooperate, and they expressed willingness to help out. When thanked for cooperation at the close of the interview, the general response was to the effect that they were glad to do it, and hoped they had been helpful. With the grinders, there was a complete reversal of attitude. They viewed the interviews as being helpful to them and expressed gratitude to the interviewer. This feeling was clearly explained by the last grinder interviewed. He announced:

> "I'm the last one to see you. I've watched the boys as they came back, and we've talked it over. They all think this is a fine idea, and I do too. They appreciate having talked to you. They say this is the first time since they came to the Base that they have had a chance to speak their piece to somebody who

was interested and who wanted to understand them."

Job Perception in the Study and Control Groups

The study of attitudes through analysis of the way in which a person makes his judgments has become an important experimental approach to the problem of motivations behind human behavior. Perception of such explicit physical dimensions as weight,[10] color,[11] geometric form,[12] and quantity,[13] have been shown experimentally to be influenced systematically by attitudinal factors. Such complex areas as prejudice,[14] group identification,[15] prestige factors,[16] ego involvements,[17] and levels of aspiration,[18, 19] also have been investigated through this approach. Level-of-aspiration experiments are concerned with how a person sets his standards and goals. Whether they are high or low, realistic or unattainable, has been demonstrated to be dependent upon his ego involvement and group status. (Sherif.) In the present study, this conceptual approach was applied to the problem of worker-morale at the air base, by the administration of the E-scale previously described.

The rationale of the E-scale is concerned with job standards, which are theoretically a function of ego-involvement. If a worker feels that his job calls for special abilities which he possesses and in which he takes pride, he will be selective in the type of person whom he would judge to be capable of achieving equal success. If, however, he has little at stake psychologically, if he is "just hiring out," as one worker put it, he would view his job as something which could be executed by an average or inferior worker. Accordingly, it was hypothesized that the ego-involved, high-morale engine testers and the welders would give significantly lower ratings, as represented by the larger numbers, than the non-involved grinders; it was further assumed that the E-scale ratings of clique welders would be significantly lower than those of the non-clique welders.

The results upheld both hypotheses. Comparisons of E-scale ratings made by engine testers and welders with those made by grinders are shown in Table I. These figures show that ratings of engine testers and welders fall significantly below the ratings of the grinders, and the differences indicate that the engine testers and welders are more selective than grinders in their judgments of the abilities required for success in their own jobs.

Table II presents the E-scale ratings of the welders divided into groups on the basis of their participation in clique membership, and also on the basis of grade. Comparison of clique and non-clique welders shows a difference in E-scale rating which is significant at the five per cent level of confidence, with the difference toward greater selectivity in judgments of job qualifications by the clique members. Divided on the basis of grade, the welders fall into two groups which are distinguished not only by a salary differential but also by differences in the nature of the work on the repetitive-diversified continuum, and by degree of skill involved. Comparison of welders divided on this basis shows no significant difference in E-scale ratings, indicating that these criteria are not the critical ones in determining degree of ego-involvement.

TABLE I

Comparison of Differences in E-Scale Ratings Made by Engine Testers and Welders with Ratings Made by Grinders

	Mean Difference	Standard Error of Difference	t	df	Significance
Total Engine Testers—Grinders	0.084	0.031	2.70	24	1%
Total Welders—Grinders	0.172	0.046	3.72	24	1%

TABLE II

Comparisons of Differences in E-Scale Ratings Made by Sub-groups among Welders

	Mean Difference	Standard Error of Difference	t	df	Significance
Clique Welders—Non-clique Welders	0.150	0.0729	2.06	24	5%
Grade 15 Welders—Grade 10 Welders	0.032	0.0519	0.63	24	NS

These findings, showing the effects of attitudes on perception, throw some light on the consistent tendencies found in the interviews of high morale groups to minimize disagreeable aspects of their jobs, while low morale groups exaggerated them. The engine testers, describing with enthusiasm their feelings of accomplishment and their enjoyment in the teamwork relationships of their jobs, made little complaint about the high noise intensity occasioned by the running jet engines, their exposure to heat and cold in the vented cells where the engines were tested, the danger of fire or explosion from the untested engines, or the fact that their work inevitably was greasy.

The clique welders, eager to describe their fascination in their work and their harmonious

TABLE III

Means and Standard Deviations of Absence Frequency, Absence Disability, Absence Severity, and Dispensary Visit Rates Among Study and Control Groups

Group	Number of Persons	Absence Frequency Rate		Absence Disability Rate		Absence Severty Rate		Dispensary Visit Rate	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Study	103	2.70	2.10	5.12	4.06	2.22	2.13	4.22	3.46
Control	104	3.34	1.95	6.83	6.57	2.22	1.44	4.49	3.10

TABLE IV

Classification of Dispensary Visit Rates

Group	Person Years of Service	*T* Total Visits	Reason for Visit							
			Occ. Ill.	Occ. Inj.	Non-Occ. Ill.	Non-Occ. Inj.	Occ. Inj. & Ill.	Non-Occ. Ill. & Injury	Ind. Hyg. Exams.	Other
Study	653.9	4.17	0.01	0.93	0.81	0.13	1.24	0.04	0.92	0.10
Control	586.8	4.62	0.07	0.92	1.63	0.20	1.32	0.06	0.31	0.07

relationships with supervisors and fellow workers, dismissed as routine the flying bits of hot slag or metal which burned them and occasionally had to be removed from their eyes.

The non-clique welders dwelled upon the usual strain, fumes, fatigue, low pay, and described the work as strenuous and unhealthful. The grinders, few of whom understood the purpose of their work, and most of whom looked forward to a transfer to another job, showed little ego-involvement. Their job standards, as measured by the E-scale, were comparatively low.

These findings may be interpreted from the experimentally demonstrated viewpoint that perception varies in accordance with attitudes. Descriptions of working conditions made previously by these employees represented actual perceptions of their work, influenced in part by motivational factors.

Absence and Dispensary-Visit Rates

One final measure of the work-effectiveness of the two groups was employed—the commonly accepted index of rates of attendance or absenteeism, number of visits to plant dispensaries, and frequency and severity of injuries. From the total number of days lost and the total person-years of service (length of employment in present position), the following rates, as defined previously, were determined: absence frequency rate, absence disability rate, absence severity rate, and dispensary visit rates. Only absences from illness or injury were recorded. From an examination of Table III it will be seen that statistically significant differences were found only in the first two rates—the Study Group demonstrated a significantly lower absence frequency and absence disability rate than did the controls. The high-morale, ego-involved engine testers were thus shown to have fewer absences per worker per year than did the welders and grinders.

A review of Table IV shows a negligible amount of occupational illness for both groups, an almost equal occupational injury rate, and a dispensary visit rate for non-occupational illness for the welders and grinders twice that for the engine testers. Visits made for "industrial hygiene examinations" were dictated by the exposure to hazardous work materials and did not represent self-motivated visits. The Study Group, because of the high noise level of the work environment, had a greater number of such examinations—in this instance, audiometric studies.

Discussion

Throughout this study, emphasis has been placed on the worker's perception of his job, and his relationship to it. Perception is a complex reaction in which are integrated all the factors, internal and external, operating at a given time. In the present problem, external factors refer to the worker's physical environment, his co-workers and supervisors, and the work itself. Internal factors refer to individual personality variables and related work experi-

ences which determine the way in which he perceives his job.

It is the operation of internal factors which makes perception a complex phenomenon which varies from perceiver to perceiver, and in the same perceiver at different times. Thus, many engine testers described their disturbance following their initial encounter with the high noise level in the test block, and their subsequent indifference to it as they became acquainted with the work and learned to like it. The noise level remained the same; the adjustment of the workers changed, and with it came a change in perception of the noise. Different welders described the same work as monotonous or varied; grinders reported the same jobs as interesting or dull. Engine testers working in extreme heat and cold said they liked being out-of-doors, while grinders complained about being "cooped up in an old air conditioned building." Workers differed significantly in their judgment of the degree of skill required by work rated by job analysis to require a comparable degree of skill.

These findings do not mean that working conditions are negligible factors which can be ignored. They do suggest that working conditions, per se, including noise, are not influential in producing morale or lack of it. The important factor is how the worker perceives the conditions under which he works. Any stress can be tolerated, if there is sufficient depth and meaning to the worker's position in his operational area. If he is accepted as a group member, if he feels he belongs, and if he believes that he is contributing to an effort of worth with which he can identify closely, then noise—even at the levels found at the Base—can be handled by the employee, and eventually turned back by him as not annoying. It has been demonstrated, in fact, that the same employee has been capable of going beyond this point of adjustment. He has—when the structuring of the group has been logical and right—been able to demonstrate a level of morale rarely found in non-hazardous work locations.

Employee Education

These findings point directly to a need for increased employee training and education. The knowledge of the principles of the jet engine, its working parts, and how his own work relates to it, would provide objective data which would enable the worker on repetitive tasks to see where his efforts fit into the picture. A further gain would be the worker's realization that he is regarded as a responsible member of his organization, whose ability was being cultivated as a useful asset. These conditions should provide the groundwork for the development of the kind of ego-involvements which in Engine Test sprang from conditions which, by fortunate chance, were inherent in the nature of the work itself.

Plant Policies

Another area in which the study suggested a need for employee education is that of plant policy. It has been noted that few of the workers interviewed could give clear statements of procedures involving loan-outs, sick leaves, distribution of overtime, raises, etc. In the absence of objective information, the worker's evaluation of these policies was based on subjective factors, biased by his own degree of morale. Experimentally, it has been demonstrated that in ambiguous situations, judgments become unstable and anxiety increases. Definite knowledge of plant policies might serve to reduce feelings of uncertainty and of the worker's being dealt with arbitrarily. Of special importance in this connection might be the problem of the anxieties about job security during slack work periods. In this plant of homogeneous workers, rumors of job cancellations or a reduction in force traveled fast, and created tensions. Definite information from supervisory personnel should help to alleviate these anxieties when the work load lightens.

Supervision

An area of central importance to worker effectiveness and morale is that of supervision. The majority of the supervisors and foremen interviewed expressed a need for more extensive training. The general feeling was that most of their experience had been "along mechanical lines," and that they were inadequately prepared to deal with personal problems. Some who were dealing with difficult morale situations recognized the problem, but said they were at a loss to understand it or provide a solution. The worker's sense of accomplishment, of responsibility, and of the importance of his work, which have been shown to be so basic to his morale, can be influenced vitally by relationships with his supervisor. A supervisory training program emphasizing the needs of the worker, the importance of group identifications, and the fostering of group consciousness by use of democratic procedure, the effectiveness of group decision, delegation of responsibility, and clarification of plant policies, should be profitable.

Summary

1. Much of the initial literature relating to the adverse effects of noise on behavior was richer in expressed theory than in pertinent documented data. The early laboratory settings did not match

our contemporary "jet age" industrial situations. Over the years, controlled studies helped move opinion away from one which viewed noise as all-harmful, to one which granted that it might be annoying but was unproductive of specific behavior response, except at levels or under conditions which masked or eliminated verbal communication. The clinical entity of occupational deafness was recognized.

2. Morale studies, meanwhile, established the importance of this factor in industrial production, and defined it as the spirit pervading a group which is enthusiastically united in the accomplishment of a common mission, with individual members whose estimates of their own prestige, status, and satisfactions are high.

3. The present study consisted of an investigation of employees laboring under extremely high noise exposures and a control group of workers subjected to normal factory noise. The problem was to determine the levels of morale within each group of workers, compare them, and isolate those factors most critically involved in determining the level of morale. The hypothesis to be tested was that not from noise or any other environmental distraction, but from the degree of ego-involvement of the individual worker in his job, springs the behavior from which morale is deduced.

4. The subjects for study were 105 civilian employees at an air force base under the Air Materiel Command. The Study Group consisted of 50 Aircraft Jet Engine Testers exposed maximally to 119 decibels at over-all level, with a Speech Interference Level of 112 decibels. The Control Group consisted of 55 men from the Parts Overhaul Section—welders and grinders—exposed to average factory noise of 76 decibels, with an S.I.L. of 58 decibels. The method of study included:

a. a Group Relations Study, carried out by personal interviews, and sociometric investigations by means of which sociograms for each group of workers were constructed;
b. the testing of job perception as a function of ego-involvement in work, by the administration of a specially devised scale; and
c. a review of illness-absence rates, injury rates, and frequency of visits to the Base medical dispensary.

5. The sociogram of the engine testers was characterized by the integration of the entire group, and although there were clique formations, the relationships within them were subordinate to the outgoing relations among them. The personal interviews gave specific evidence of a common motivation toward a strongly felt group goal—turning out a "good" engine, which was a joint responsibility of the group, and which was important to them. Work was done as a team. Because of the high degree of motivation, objectively unpleasant features of the work were minimized. The engine testers were judged to have high morale.

6. The ego-involvement of the welders was shown to be with their skilled craft rather than with a group goal. Work was performed alone. Their sociogram shows a clear division between a tightly-knit clique on the one hand, based largely on off-the-job social contacts, and the rest of the group. Non-clique welders enjoyed their work and minimized the job hazards, while non-clique welders registered many complaints about the same kind of work, and indicated insecurity and confusion with regard to plant policy and personnel practices. The clique welders demonstrated high morale, while the non-clique welders did not.

7. Grinders also worked alone, but shared neither the craft identification of the welders nor the involvement in a common production goal of the engine testers. Their sociogram demonstrated a sparseness of interrelationships and depicted a lack of group consciousness. Most disliked their work, and many wanted to transfer. There was no meaningful whole on which they were working, and they did not know the purposes or worth of their efforts. There was no demonstrated ego-involvement or identification with the work. Although their working conditions were less hazardous and unpleasant than engine testing, they complained far more of conditions and of poor in-plant communication. Their morale was deduced to be low.

8. Job perception of all workers was measured by the E-scale, devised to determine if groups will differ, on the basis of morale, in their judgment of the standards related to their work. Results demonstrated that engine testers and welders were more selective in judgment of job qualifications; there were no significant differences in E-scale ratings between welders of different grade levels, but there were between clique and non-clique welders. The low morale of the grinders was expressed further and matched by the E-scale. For all groups, the E-scale testing underscored the fact that perception varies with attitudes. Descriptions of working conditions—good or bad—represented actual perception of their work, influenced in part by motivational factors.

9. Data were secured from personnel and clinical records in order to correlate certain rates of the two groups. The absence frequency, absence disability, absence severity, and dispensary visit

rates were compared. The high-morale, ego-involved engine testers were shown to have fewer absences per worker per year than did the welders and grinders. Occupational illness and occupational injury rates for the Study and Control Groups were almost equal, but the dispensary visit rate for non-occupational illness of the welders and grinders were almost twice that of the engine testers.

Conclusions

1. Adverse factors such as noise, exposure to inclement weather, slippery operational areas, and potential explosiveness of work materials, per se, do not determine morale or affect behavior on the job.

2. Morale results from the worker's perception of his working conditions and his job, and the manner in which the job is perceived is a function of ego-involvement.

3. Associated with ego-involvement are: a feeling of "belongingness," a sense of responsibility, and an opportunity to contribute knowingly to a worthwhile effort.

4. A program of training can contribute greatly to an awareness of the needs of workers, and the kinds of satisfactions they want from their jobs.

5. Through this awareness and understanding, workers will be given a feeling of respect, of worthwhileness, of importance—of being wanted.

6. Through a comparable program, workers can be apprised of personnel policies and practices, so that a continuing knowledge can allay feelings of insecurity and develop a sense of stability. More important than the knowledge is the feeling that one is a needed part of the organization.

7. With these goals attained, illness-absenteeism and excessive visitation to the medical department should be reduced, and support of the industrial group's efforts—production—should be a natural and logical conclusion.

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M. L. Keplinger. The Evaluation of Toxic Materials Using Humans.
T. B. Clarkson. The Pigeon as an Experimental Animal

August 8—
Jack Frawley, Chairman
R. B. March. Metabolism of Organophosphorus Pesticides.
W. J. Hayes, Jr. Metabolism of Chlorinated Hydrocarbon Insecticides in Mammals.
Louis Lykken, Chairman
M. R. Zavon. Interpretation of Animal Toxicity Data in Human Safety Evaluation of Pesticides.
E. M. Boyd. Evaluation of Acute Toxicity.

August 9—
C. Boyd Shaffer, Chairman
Philippe Shubik. Evaluation of Carcinogenic Effect of Food Additives.
J. A. Miller. A New Metabolic Approach in the Study of Carcinogenic Amines.
J. Siegel, Chairman
W. L. Anderson. The Chemical Phase of Air Pollution in Confined Spaces.
W. E. McConnaughey. Engineering Aspects of Atmosphere Control.

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J. H. Draize. Appraisal of the Safety of Substances Applied Topically to Skin and Mucous Membranes.
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W. Lammers. Discussion of the Margarine Additive Intoxication.
P. E. Johnson, Chairman
W. J. Darby. Food Additives as an International Problem.

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